Life-Cycle Costing Workshop for Energy Conservation in Buildings: Student Manual

Sieglinde K. Fuller
Stephen R. Petersen

U.S. DEPARTMENT OF COMMERCE
Technology Administration
National Institute of Standards
and Technology
Building and Fire Research Laboratory
Office of Applied Economics
Gaithersburg, MD 20899

TABLE OF CONTENTS

PREFACE

This Student Manual for the *Life-cycle Costing Workshop for Energy Conservation in Buildings* is a workbook for a two-day course on life-cycle cost (LCC) analysis developed by the National Institute of Standards and Technology (NIST) for the U.S. Department of Energy, Federal Energy Management Program (FEMP). The methodology and procedures in this manual are consistent with 10 CFR part 436 and its amendments, which provide guidelines for the economic analysis of investments in energy conservation and renewable resources for federal buildings.

The purpose of the workshop is to provide energy managers with the knowledge and skills they need to perform economic analyses of capital investments in energy conservation quickly and correctly. The analytical methodology presented is equally useful to government and private sector investments. Under the sponsorship of FEMP, the Office of Applied Economics (OAE) at NIST has conducted this workshop for both government and private sector participants several times each year for the past 10 years in various locations throughout the United States, as well as in Europe and Korea.

Starting in 1995, FEMP and NIST have been encouraging "FEMP-qualified" LCC instructors to teach this same course, using this student manual as the basis of the course curriculum. The use of "FEMP-qualified" LCC instuctors for this purpose can greatly expand the usage of LCC methodology to evaluate the cost effectiveness of energy conservation projects in the United States, both in government and in the private sector.

This Student Manual is organized into 10 teaching modules and provides hard copies of the visual materials (slides) that are presented in each module. These visual materials are updated annually to reflect changes in the federal discount rate and projected energy price escalation rates used in federal LCC analyses of energy conservation projects. The visual materials are shown in the order that they are presented, in order to facilitate note taking by the students. Review materials for each module are presented at the end of the module, as well as an exercise based on the lecture. We recommend that the students work in small groups to solve these exercises rather than working individually.

Other materials used in the LCC workshop include:

Energy Price Indices and Discount Factors for Life-Cycle Cost Analysis 1996, Annual Supplement to NBS Handbook 135 and Special Publication 709, NISTIR 85-3273-10, Stephen R. Petersen, National Institute of Standards and Technology, Gaithersburg, MD, October 1995 (updated annually on or about October 1).

Discount Factor Tables for Life-Cycle Cost Analyses, NISTIR 89-4203, Stephen R. Petersen, National Institute of Standards and Technology, Gaithersburg, MD, December 1989.

Present Worth Factors for Life Cycle Cost Studies in the Department of Defense (1996), NISTIR 4942-3, Stephen R. Petersen, National Institute of Standards and Technology, Gaithersburg, MD, October 1995.

The NIST "Building Life-Cycle Cost Program (Version 4.3) User's Guide and Reference Manual, NISTIR 5185-3, Stephen R. Petersen, National Institute of Standards and Technology, Gaithersburg, MD, October 1995.

Note: The terms "Present Value Factor" and "Present Worth Factor" have identical meaning when used in NIST publications related to engineering economics. These terms have been used somewhat interchangeably in previous editions of the student workbook and in the documents referenced above. In the future these publications will use the term "Present Value Factor" in conformance with the terminology used in the building economics standards published by the American Society for Testing and Materials.

ACKNOWLEDGMENTS

ABBREVIATIONS AND SYMBOLS

A_i annual amount in year I

A_0 annual amount as of beginning of study period

AIRR   adjusted internal rate of return

ASEAM   A Simplified Energy Analysis Method (computer program)

BLCC   Building Life-Cycle Cost (computer program)

C_i cost incurred in year i

CERL   Construction Engineering Research Laboratory
                (U.S. Corps of Engineers)

Δ delta (change in ...)

d *real discount rate*

D   nominal discount rate

DoD   Department of Defense

DOE   Department of Energy

DPB   discounted payback

e real rate of energy price escalation

E   nominal rate of energy price escalation

EPRI   Electric Power Research Institute

F_i future amount in year i

FEMP   Federal Energy Management Program

HVAC   heating, ventilating, and air conditioning

IRR   internal rate of return

LCC   life-cycle cost

LPG   liquified petroleum gas

MARR	minimum acceptable rate of return
MBtu	million Btu
MILCON	Military Construction
NS	net savings
NBS	National Bureau of Standards
NIST	National Institute of Standards and Technology (formerly NBS)
OM&R	operation, maintenance and repair
P	present amount
PV	present value
QI	BLCC Quick Input (computer program)
SCA	single compound amount (factor)
SIR	savings-to-investment ratio
SPB	simple payback
SPV	single present value (factor)
UPV	uniform present value (factor)
UPV*	modified uniform present value (factor)

COURSE OBJECTIVES

- Know how to *use economic analysis to improve capital investment decisions* related to energy conservation in buildings

- Know the *common methods and assumptions required* for life-cycle cost analyses of energy-related investments in federal buildings

- Know how to *use the BLCC program* for life-cycle cost analysis

COURSE OVERVIEW

DAY ONE

The course begins with a discussion of the types of economic decisions usually required by engineers, architects, and building managers concerned with improving the energy performance of buildings. An overview is given of how life-cycle costing and related methods of economic analysis can improve energy-related investment decisions. The elements of performing a life-cycle cost evaluation are explained. Emphasis is placed on clarifying those issues which often confuse practitioners. Issues include why it is necessary to adjust cash flows for the time-value of money and how to do it, how to estimate costs and savings, and how to handle inflation. Sample exercises are provided. Students are shown, step-by-step, how to compute Life-Cycle Costs, Net Savings, and the Savings-to-Investment Ratio. Federal criteria for performing economic evaluations of energy-related building projects are presented. Students are asked to solve sample problems. The BLCC computer program is introduced. Students are expected to use the program to solve a problem similar to the one presented in the workshop.

DAY TWO

The second day returns to the relationship between life-cycle costing and supplementary measures of economic evaluation: Net Savings, Savings-to-Investment Ratio, Adjusted Internal Rate of Return and Discounted Payback. Coverage is broadened to solve more complex problems: finding optimal efficiency levels and optimal designs for independent and interdependent building systems, and allocating limited budgets among projects. In a second computer lab, students solve an additional problem using the Quick Input Version of BLCC. The issue of uncertainty is discussed and guidance is given on how to deal with it in a life-cycle cost analysis. A combined review/question and answer session concludes the two-day course on life-cycle costing.

COURSE AGENDA

DAY 1

TOPIC

A.   ECONOMICS CAN IMPROVE DECISIONS

B.   WHAT YOU NEED TO GET STARTED

C.   ADJUSTING CASH AMOUNTS TO PRESENT VALUE

D.   CALCULATING LIFE-CYCLE COSTS

E.   BLCC COMPUTER PROGRAM

DAY 2

F.   CALCULATING SUPPLEMENTARY ECONOMIC MEASURES

G.   EVALUATING EFFICIENCY LEVELS AND DESIGN ALTERNATIVES

H.   ALLOCATING INVESTMENT FUNDING AMONG COMPETING PROJECTS

I.   USING THE BLCC QUICK INPUT PROGRAM (QI)

J.   DEALING WITH UNCERTAINTY AND RISK IN LCC ANALYSIS

INSTRUCTORS' PROFILES

STEPHEN R. PETERSEN

Steve Petersen is an economist in the Office of Applied Economics at the National Institute of Standards and Technology. His area of research has been largely focused on engineering economics, energy conservation in the design of new residential buildings, and the design and selection of heating and cooling systems for buildings. He has published over 30 articles, reports, books, and computer programs related to these subjects. He is a member of the Building Economics Subcommittee in the American Society for Testing and Materials (ASTM), and has played a key role in the development of the building economics standards and related computer programs published by that group. In 1980 Mr. Petersen was accepted into the President's Executive Exchange Program and worked in the Engineering and Research Division of the Carrier Corporation in Syracuse, NY, for one year.

A graduate of the University of California (B.A., 1969) and UCLA (M.A., 1972) in economics, Mr. Petersen also served four years in the USAF as a Russian Interpreter, and worked several years as an analyst for the Defense Department in Washington, DC.

SIEGLINDE K. FULLER

Linde Fuller is an economist in the Office of Applied Economics of the National Institute of Standards and Technology. Her areas of expertise include benefit-cost analysis, decision analysis, and public sector pricing. She has also collaborated with Rosalie Ruegg and Steve Petersen in developing economics courses and technical manuals for life-cycle cost evaluation of government and private sector investment projects. Recently she has been engaged in research to develop a pricing model for publicly produced private goods and services of the type supplied by NIST. She has published manuals, reports, and articles related to these subjects.

Prior to joining NIST in 1979 as an economist, Ms. Fuller studied languages and linguistics and worked as a translator and interpreter for industry representatives to the European Common Market, at trade exhibitions, and for commercial enterprises in Germany, Canada, France, and the U.S. She received a B.A. in economics from the University of Maryland (1979), and an M.Ph. in economics (Public Finance and International Economics) from The George Washington University (1985), where she is at present a Ph.D. candidate.

INTRODUCTION

Why this course?

The energy crises of the 1970's, higher energy prices, and environmental concerns focused our attention on the critical need to include energy conservation as a major performance objective in the design or rehabilitation of buildings. The Federal Government, as owner and operator of nearly a half-million buildings and the nation's largest user of energy, must play a leadership role in improving the energy efficiency of our nation's building stock.

Congress and the President, through legislation and executive order, have mandated energy conservation goals for federal buildings and required that these goals be met using cost-effective measures. These measures include both improved operating procedures and the incorporation of energy conservation features in the design of new and existing buildings. The primary criterion mandated by Congress and the President for assessing the cost effectiveness of energy conservation investments in federal buildings is the minimization of life-cycle costs. They have also instructed the Federal Government to make available to the private sector, methods, computational tools, and data developed in the Federal Energy Management Program.

Scope

This course is designed for both public and private sector energy managers. Its purpose is to provide an overview of the life-cycle cost method, specific requirements for federal building applications, sources of data, and computer tools which can greatly simplify the analytical requirements of a life-cycle cost analysis. The life-cycle cost method and related measures of economic performance are presented in a traditional engineering economics context.

The principles of economic evaluation taught in this course are widely applicable to investment decisions in both the public and private sectors. The investment decisions of most relevance to this course are: (1) Is the higher initial cost of a project justified by lower operating costs in later years? and (2) Of several potential alternative investments, which is the most economical in the long run? While this course focuses on investments in energy conservation and renewable resources in federal buildings, the principles are equally applicable to projects undertaken by state and local governments, non-profit organizations, and for-profit companies and corporations.

About this manual

This manual is intended as both an in-class workbook and as a future source of reference and review. Like the course, the manual is divided into 11 major modules which group materials by subject matter. Each module begins with the learning objectives for that module. The visual materials (slides) presented in the workshop are shown on the following pages, so that the student can concentrate on the lecture with a minimum of note taking. At the end of each module, a summary of the lecture for that module is given, keyed to the visual materials. For most modules an exercise is provided to be solved by the students in the classroom. Students are generally encouraged to work in small groups when solving these classroom exercises.

This course also includes two computer labs which provide an opportunity for hands-on experience with the NIST Building Life-Cycle Cost (BLCC) program and BLCC Quick Input Program. Exercises similar to those solved in the classroom are provided for solution with the computer programs. An overview of the programs is presented before each of these labs, and instructors are available in the lab to assist students and answer questions.

ECONOMICS CAN IMPROVE DECISIONS

MODULE A   Lecture, Discussion

Objectives

At the conclusion of this module, you will be able to

- Give examples of decisions affecting energy consumption in buildings, which can be improved by using economic analysis

- Explain the concept of life-cycle cost analysis

- Understand the concept of economic optimization

Investment Decisions Requiring Economic Analysis

Types of Decisions

- Accept / reject projects

- Optimal energy efficiency level

- Optimal system selection or design

- Optimal combination of interdependent systems

- Prioritization of independent projects

NOTES:

Making Cost-Effective Decisions

Basic Economic Criterion for Capital Investments That Reduce Future Operating Costs
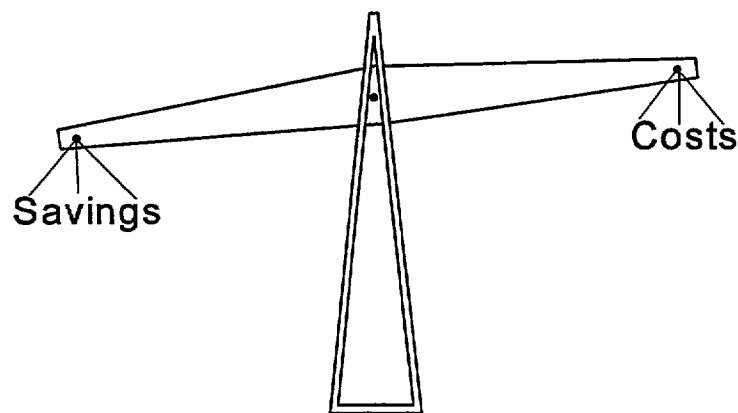
Savings

Costs

Savings must be greater than costs

NOTES:

Making Cost-Effective Decisions
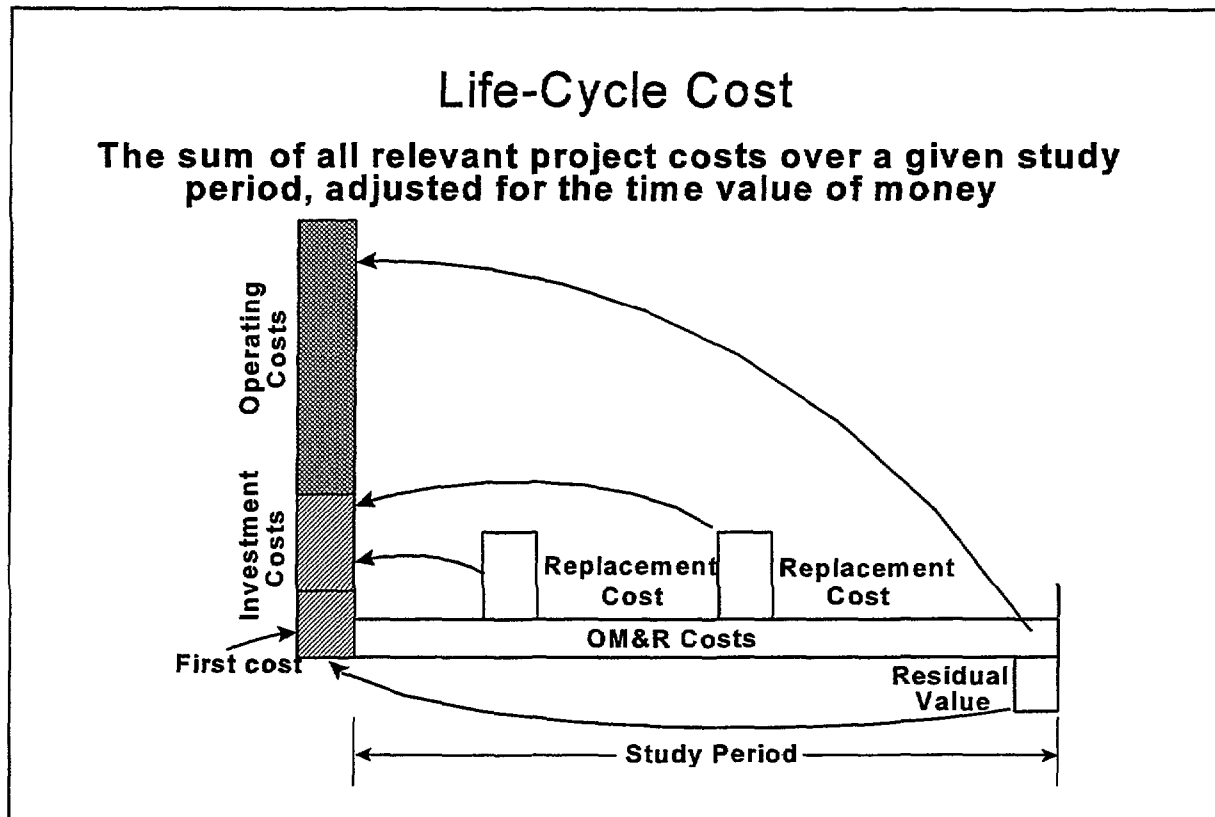
NOTES:

Making Cost-Effective Decisions

Life-Cycle Costs of Two Alternatives
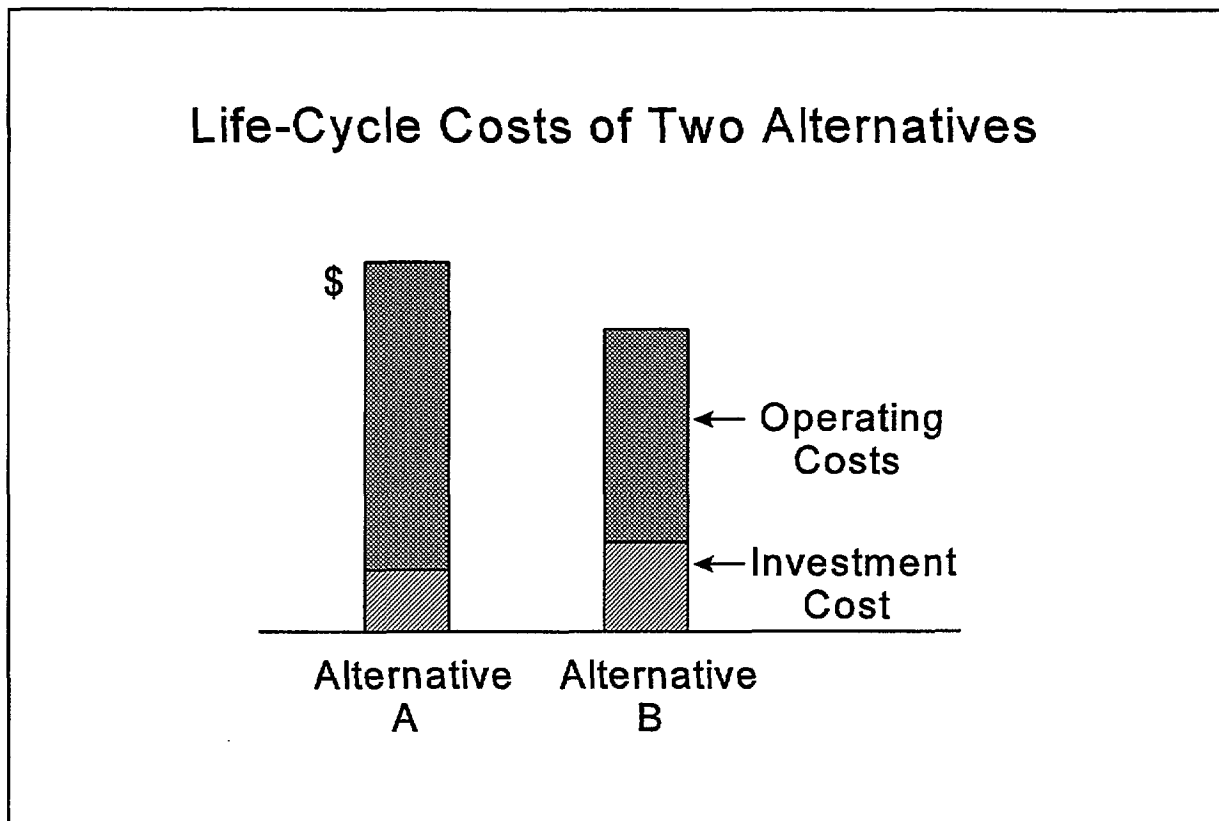
NOTES:

Making Cost-Effective Decisions

Initial Cost and 20-year Operating Cost of a Motor

88% Energy Cost $6,500

7% Maint. & Repair $500

5% Purchase Cost $400
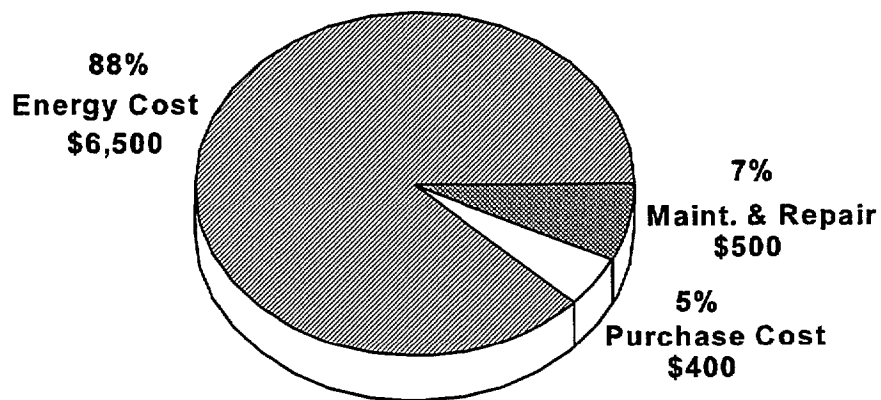
NOTES:

Making Cost-Effective Decisions

Initial Cost and 15-year Operating Cost of a Heating System

68%
Energy Cost
$6,450

9%
Maint. & Repair
$900

23%
Purchase Cost
$2,200
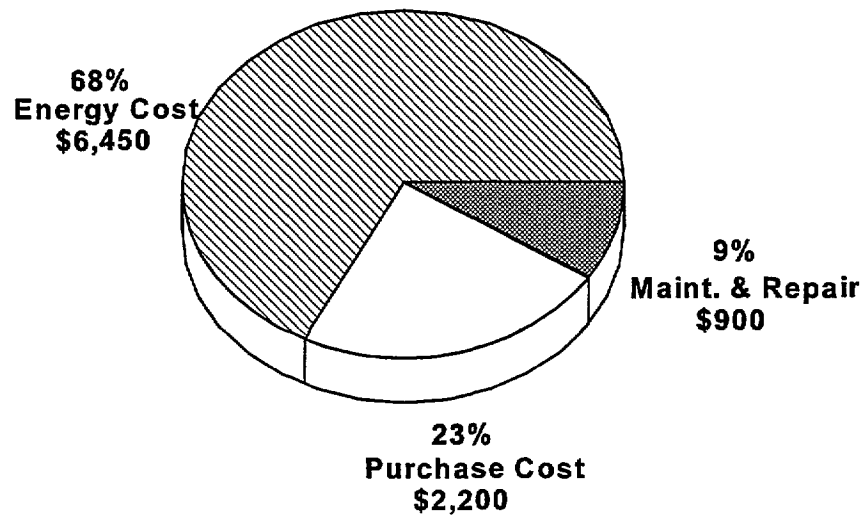
NOTES:

Making Cost-Effective Decisions

Investment and Operating Costs Related to the Energy Efficiency of a Building System
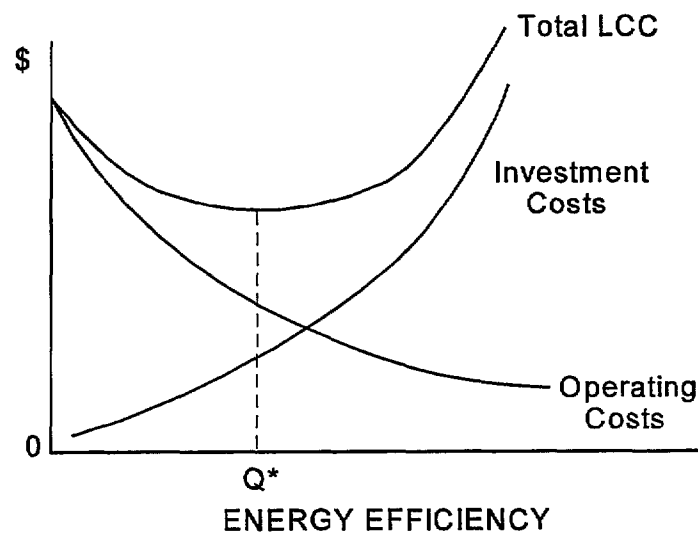
NOTES:

Making Cost-Effective Decisions
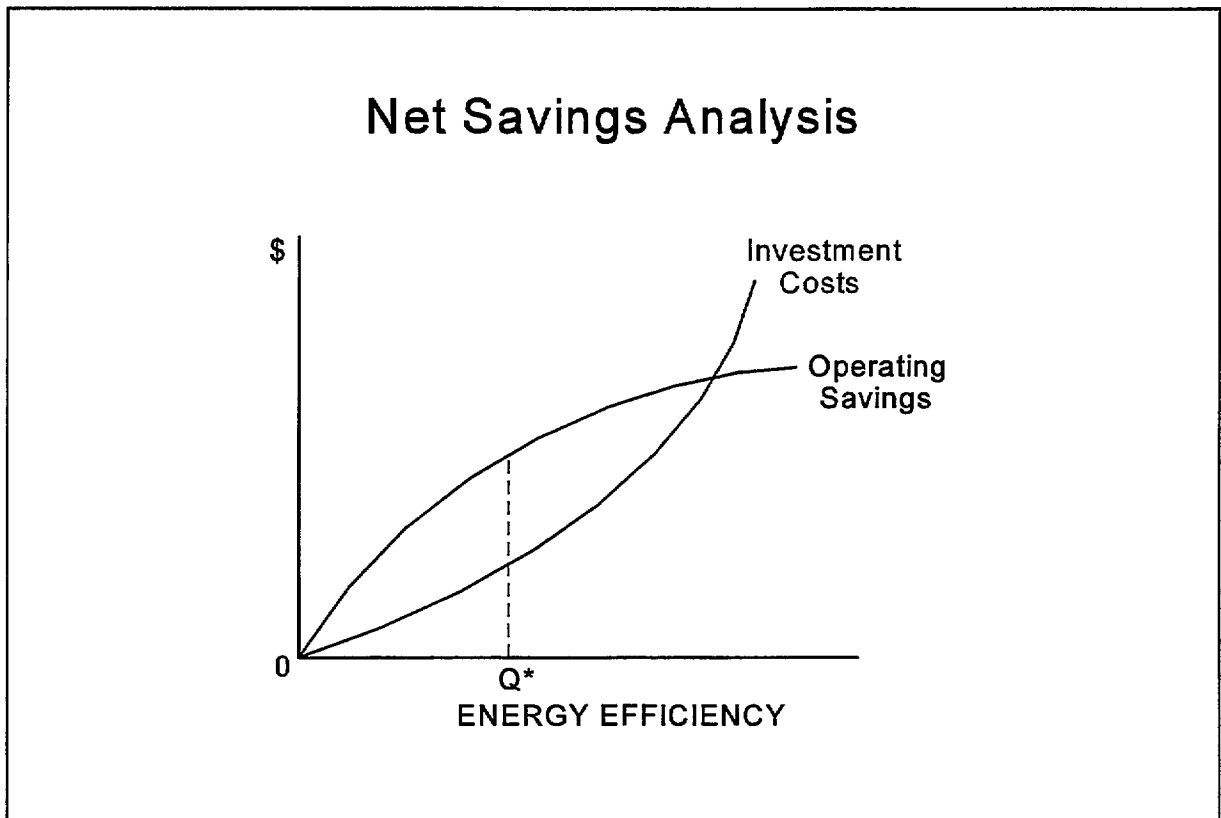
Net Savings Analysis

NOTES:

Making Cost-Effective Decisions

Incremental Analysis:
Incremental Savings vs. Incremental Cost

$

Incremental
Investment

Incremental
Savings

Q*
ENERGY EFFICIENCY
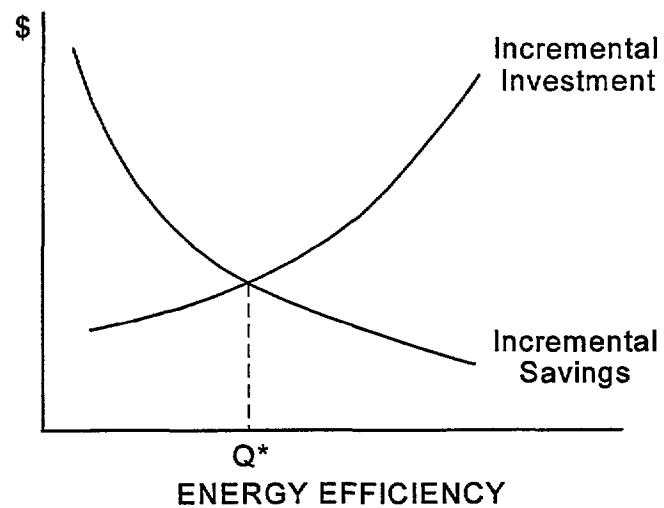
NOTES:

Supplementary Measures of Economic Performance   Slide A10

Supplementary Economic Measures

- Net Savings (NS)

- Savings-to-Investment Ratio (SIR)

- Adjusted Internal Rate of Return (AIRR)

- Payback Period (PB)

NOTES:

LCC Procedure

How to Perform an LCC Analysis

- Identify alternatives
- Specify data requirements and establish assumptions
- Estimate costs in dollars
- Adjust costs for time value of money
- Compute total LCC for each alternative
- Select alternative with lowest LCC
- Compute supplementary measures
- Consider uncertainty in input values

NOTES:

INVESTMENT DECISIONS REQUIRING ECONOMIC ANALYSIS

Types of Decisions   Slide A1

Five types of investment decisions related to energy conservation in buildings are shown here, to which economic analysis can be usefully applied. This course focuses on the appropriate methods for solving each of these problem types, especially as they relate to energy conservation in the design and retrofit of buildings.

An **accept/reject project** is a project that is optional from a building design standpoint and can be either implemented or not, depending on whether or not it is a good investment. A good example is the installation of standard storm windows over existing single-pane windows in a house. The comfort level of a house can be maintained at an acceptable level with or without storm windows, but with storm windows installed much less energy will be used. (If several options are available with different levels of energy performance, then this becomes a decision about the optimal efficiency level.)

The **optimal efficiency level** refers to the problem of selecting the most cost-effective level of energy performance for a building system. For example, attic insulation can be installed over a wide range of thermal resistance levels, an air conditioner can have a wide range of seasonal efficiency ratings, and a solar heating system can have a wide range of collector areas.

Optimal system selection refers to the problem of selecting the most cost-effective system type for a particular application. System selection can directly impact the energy performance of a building. Examples include the choice of the heating and cooling system types for a building (e.g., electric heat pump or gas furnace with electric air conditioning), wall design (e.g., masonry or wood frame), or even insulation type (e.g., rigid foam or mineral wool).

The **optimal combination of interdependent projects** refers to the problem of selecting two or more building systems at the same time, recognizing that the implementation of one system will have significant effects on the energy savings potential of the other, and vice-versa. For example, installing a high-efficiency furnace will reduce the energy savings potential of storm windows, while installing storm windows will reduce the energy savings potential of installing a high-efficiency furnace.

The **prioritization of independent projects** is required when a number of cost-effective energy conservation investments have been identified but not enough funding is available to implement all of these projects. Economic analysis allows the ranking of these projects in decreasing order of cost effectiveness as a guideline to allocating available funding.

MAKING COST-EFFECTIVE DECISIONS

Savings and investment costs
Slide A2

The basic criterion for determining whether a design alternative that increases capital investment and lowers future operating costs is cost effective is that **the savings generated by the investment must be greater than the additional investment cost**. The number of years over which the savings are accumulated and the weighting of future costs (or cost savings) relative to present costs are major considerations in life-cycle cost (LCC) analysis.

Life-cycle cost
Slide A3

The LCC concept requires that **all costs and savings related to a design decision be evaluated over a common study period and be adjusted for the time value of money** before they can be meaningfully compared. Choosing building systems on the basis of first cost alone can increase the long-run owning and operating costs of a building. For example, the purchase of a low-efficiency heating system, while initially less expensive than a more efficient system, will incur higher energy costs when in use. The difference may be significant since for many building systems only a small part of the life-cycle cost is attributable to the initial purchase price. The greater part is usually attributable to ongoing operating, maintenance, repair, and energy costs.

NOTE: When benefits are received as increased income (say rents) or improved level of service (say more office space) we usually call this a **benefit-cost analysis**, and we try to find the design with the greatest profit (in the private sector) or the greatest net benefits (in the public sector). However, when benefits are primarily realized as reduced operating costs with little or no change in the level of service, we use **life-cycle cost analysis**, and we try to find the design with the lowest life-cycle cost. Energy conservation analyses deal mostly with investment costs and operating costs, and we therefore use the LCC model.

Comparing alternatives
Slide A4

From a decision standpoint, **the LCC of a design alternative only has meaning when it is compared against the LCC of a base case**. For example, Alternative B has a higher investment cost but lower operating-related costs than Base Case A, although both are expected to perform equally well with regard to their basic purpose. Since the sum of investment cost plus operating cost (including energy costs) for alternative B is less than that for A, alternative B is the more cost-effective choice. Note that in an existing building, the base case alternative (i.e., the existing design) may not require any investment; it may be the "do nothing" alternative. In that case, the life-cycle cost of the base case is made up entirely of operating-related costs, which must be compared against the combined investment and operating costs of the alternatives considered. In other cases (e.g., a new building design) the base case may be the design with the lowest first cost or the minimum level of performance that satisfies building code requirements.

Investment costs and long-run operating costs   Slides A5 and A6

The pie charts demonstrate that **it is important to take into account energy efficiency when purchasing equipment**. The first of these pie charts shows the estimated costs over 20 years of owning and operating a 10-horsepower electric motor. Purchase costs comprise only five percent of the overall costs of the motor over its expected life, whereas energy costs comprise 88 percent. In this example, increasing the efficiency of the motor from 75 percent to 90 percent is estimated to add about $100 to its purchase price but to reduce the LCC by about $1,000. The second pie chart shows the relationship between purchase costs and energy costs for an oil-fired furnace to heat a 2,000 square foot house in the Washington, DC, area. The estimated fuel costs over 15 years amount to two-thirds of the total life-cycle costs, whereas the initial purchase costs make up only 25 percent of the total.

Minimizing total owning and operating costs   Slide A7

This graph compares the owning and operating costs associated with a wide range of energy efficiency levels for a building system (e.g., exterior wall insulation or air conditioner efficiency). The curves shown in this slide are quite typical of energy conservation investments. Generally, as the level of energy efficiency increases, the initial cost increases at an increasing rate. Lower levels of efficiency can generally be achieved at low cost, but as the efficiency level is increased, structural, mechanical, or design modifications must be made to accommodate the added components. This quickly adds to the initial cost. For example, to increase the effective thermal resistance value of a wall, the wall thickness must be increased or a more costly type of insulation must be used; or, in the case of air conditioners, significantly larger heat exchangers or more costly compressors must be used. For some systems, such as fossil-fired furnaces, there are practical limits to the extent to which efficiency can be increased, causing the investment cost curve to bend sharply upwards.

The operating cost curve in the graph shown is typical for most energy consuming systems. As the energy efficiency of the system is increased, energy consumption is decreased, but at a decreasing rate. In fact, energy consumption is generally inversely proportional to energy efficiency so that additional units of improvement generate less savings than the ones before. For example, increasing the thermal resistance value of attic insulation from R-30 to R-40 only saves about 18 percent as much energy as increasing the level from R-10 to R-20.

The total cost curve is the vertical summation of the investment cost and operating cost associated with any level of energy efficiency. **The lowest point on the total cost curve determines the level of energy efficiency that minimizes life-cycle costs, Q*.** It is important to recognize that there are a number of factors which contribute to this result. For example, longer study periods, more severe climates, lower conservation costs (say through technology improvements), and higher energy prices all tend to result in a higher level of energy efficiency becoming cost effective.

Maximizing net savings   Slide A8

This graph shows that the most cost-effective level of energy conservation can also be determined by finding the level which maximizes net savings, the difference between total costs and total savings. This slide shows two curves, the investment cost curve, which is identical to that shown in the previous slide, and a savings curve. The savings curve is determined by taking the difference between the operating cost at the zero level of investment and the operating cost at any other level of investment on the graph.

Note that in the graph of slide A8, total savings are greater than total costs anywhere between the origin and the point where the two curves cross. Thus we might conclude that any level of investment between these two points is justified. But in fact the **economically optimal** level of energy efficiency is that level for which **net savings is greatest**, again Q*. This is the same point that was determined by finding the level with the lowest LCC. This is not surprising if you recognize that net savings at any point along the horizontal axis of the graph in slide A7 is the difference between the LCC of the base case (measured at the zero investment level) and the LCC of the alternative at that point. Thus the energy efficiency level with the lowest LCC must have the highest net savings. By contrast, at the point where investment cost just equals savings (slide A8) you are no better off than you were at the origin, since in both cases net savings is zero.

Incremental savings versus incremental costs   Slide A9

This graph provides an additional look at the relationship between the investment cost curve and the operating cost curve. Here incremental costs and incremental savings are plotted. Each additional unit of energy efficiency results in smaller and smaller increments in savings and greater and greater additions to cost. The shape of these curves is quite typical: conservation investment costs are increasing at an increasing rate and energy savings are decreasing at a decreasing rate. **The point where these two curves cross determines the economically optimal level of energy efficiency, again Q*, the point at which the last increment in cost increases savings by the same amount.** This is the same point, Q*, found by minimizing LCC or maximizing net savings. At any point to the left of Q*, incremental savings are higher than incremental costs, so that **increasing** the energy efficiency level will reduce life-cycle costs and increase net savings. At any point to the right of Q*, the intersection, incremental savings are less than incremental costs, so that **reducing** the energy efficiency level will reduce life-cycle costs and increase net savings.

It is essential to recognize that all three of these methods arrive at the same optimal level of energy efficiency. **In general, if the LCC methodology is applied correctly, the same result will be obtained regardless of whether the lowest LCC or the maximum net savings is used.** Economists refer to the level of investment where life-cycle cost is minimized and net savings is maximized for a given project as the "economically efficient" level of investment.

The above treatment of costs and savings assumes that the energy efficiency of building systems can be improved in a continuous fashion. In fact, commercially available systems are rarely available in a continuous range of efficiency ratings. However, the underlying concepts shown here are valid even when efficiency improvements come in "step" form. That is, the alternative with the lowest LCC will be the most cost-effective choice, given that it satisfies the other performance objectives of the system. **In almost every case, finding the alternative with the lowest LCC will provide sufficient information to choose the economically efficient level of investment.**

SUPPLEMENTARY MEASURES OF ECONOMIC PERFORMANCE
Slide A10

Supplementary measures of economic performance can be used to determine the comparative cost effectiveness of capital investment. Several widely used measures are presented in this workshop. These are **Net Savings, Savings-to-Investment Ratio, Adjusted Internal Rate of Return, and Payback Period**. Except for the Payback Period, these measures are consistent with and build upon the Life-Cycle Cost methodology. All of these supplementary measures are comparative rather than absolute measures of performance because they are only meaningful in relation to an alternative course of action, i.e., the base case.

Net Savings (NS) is generally expressed in dollars. For a project alternative to be cost effective with respect to the base case it must have net savings greater than zero. Even with a zero net savings, the minimum required rate of return (MARR) has been achieved because the required rate of return is built into the net savings computation.

The *Savings-to-Investment Ratio (SIR)* is a dimensionless measure of performance (i.e., it has no units). In general, as long as the SIR of an alternative compared with a base case is greater than 1.0, the alternative is considered cost effective. Again, the MARR is built into the LCC analysis, so that even at an SIR of 1.0, the project yields the required rate of return.

The *Adjusted Internal Rate of Return (AIRR)* is calculated as a percent. This is the annual rate of return on investment generated by the project alternative relative to the base case. In general, the AIRR must be greater than the MARR to be considered cost effective. (The AIRR is a modified version of the Internal Rate of Return (IRR), adjusted for the reinvestment rate for saved cash flows.)

The *Payback (PB) Period* is a measure that is not generally consistent with the LCC methodology. PB is measured as the time needed to recoup the initial investment of an alternative relative to the base case. If the PB incorporates the time-value of money, it is called **Discounted Payback (DPB)**. If it does not include the time-value of money, it is called **Simple Payback (SPB)**. The use of PB as a decision criterion should generally be restricted to that of a screening tool. That is, if the payback period for an energy project is expected in a relatively short time compared to its expected life and no additional costs are expected after payback is achieved, then a full LCC analysis may not be needed.

However, in practice PB is frequently used to reject projects which may be cost effective in the long run (i.e., from a life-cycle cost standpoint) but do not meet the short-term objectives of the investor.

HOW TO PERFORM AN LCC ANALYSIS

Slide A11

The basic steps of an LCC analysis are to

-        identify the alternatives under consideration,
-        specify the data requirements and establish assumptions,
-        estimate the costs in dollars,
-        adjust costs for time value of money,
-        compute total LCC for each alternative, and
-        choose the alternative with the lowest total life-cycle cost.

Depending on the circumstances, you may also want to calculate supplementary measures of economic performance, perform an uncertainty assessment, and add a narrative describing non-economic issues. All of these steps will be covered during the workshop.

WHAT YOU NEED TO GET STARTED

MODULE B Lecture, Discussion, Exercises

Objectives

At the conclusion of this module, you are expected to be able to

- Define the problem and state the objective

- Decide on level of effort

- Choose method of documentation

- Identify feasible alternatives

- Specify data requirements

- Identify data sources

- Select the study period

- Draw a cash-flow diagram

Taking Care of the Preliminaries

Preliminaries

- Define problem and state objective
- Decide on level of effort
- Choose method of documentation

NOTES:

Identifying Feasible Alternatives

Choose Alternatives

- Good alternatives ESSENTIAL
- Must meet performance requirements
- Credit for extra benefits

NOTES:

Specifying Data Requirements   Slide B3

Relevant Effects

- Amounts that change
- Significant amounts
- Not "sunk" costs or benefits

NOTES:

Specifying Data Requirements

Typical Costs or Benefits

■ Investment-related:
- Acquisition Costs
- Replacement costs
- Residual value

■ Operational:
- Operating and maintenance costs
- Repair costs
- Energy costs

■ Other:
- Revenue
- Utility rebates
- Tax credits
- Nonquantifiables

NOTES:

Estimating Cash Flows   Slide B5

Estimate Costs in TODAY'S Prices

- Initial costs and replacements
    - Supplier quotes
    - Catalogues
    - Databases

- Maintenance and repair costs:
    - Databases
    - Professional experience

NOTES:

Suggested Cost Estimating Guides for LCC Analysis*

BOECKH UNDERWRITER'S VALUATION MANUAL
E. H. Boeckh Co., American Appraisal Association, Inc.
525 E. Michigan St., Milwaukee, WI 53201
(414) 780-2800

BNI BUILDING NEWS
BNI Publications
3055 Overland Ave., Los Angeles, CA 90034
(319) 202-7775

CERL M&R DATABASE
USACE Engineer Division HV
CEHND-ED-ES (Terry Patton)
P.O. Box 1600, Huntsville, AL 35807-5301
(205) 895-3373

DOLLARS AND CENTS OF SHOPPING CENTERS
The Urban Land Institute
625 Indiana Ave., N.W., Ste. 400, Washington, DC 20004-2930
(202) 624-7000

THE DOWNTOWN & SUBURBAN OFFICE BUILDING EXPERIENCE EXCHANGE REPORT (EER)
Building Owners & Managers Association International (BOMA)
1201 New York Ave., N.W., Ste. 300, Washington, DC 20005
(202) 408-2662

MEANS BUILDING CONSTRUCTION COST DATA
MEANS FACILITIES M&R COST DATA
MEANS FACILITIES MAINTENANCE AND REPAIR COST DATA
R. S. Means Co., Inc.
100 Construction Plaza, Box 800, Kingston, MA 02364-0800
(617) 585-7880

NATIONAL CONSTRUCTION ESTIMATOR
BUILDING COST MANUAL
BERGER BUILDING COST FILE
Craftsman Book Company
P.O. Box 6500, Carlsbad, CA 92008
(619) 438-7828

RICHARDSON'S GENERAL CONSTRUCTION ESTIMATING STANDARDS
RICHARDSON'S PROCESS PLANT CONSTRUCTION ESTIMATING STANDARDS
Richardson Engineering Services
P.O. Box 9103, Mesa, AZ 85214-9103
(602) 497-2062

*Most of the listed publishers issue additional, more specialized cost guides.

Estimating Cash Flows

Estimate Costs in TODAY'S Prices

- Energy Costs:
  Quantity:
  - Manual estimating
  - Computer programs
  Prices:
  - Current rates
  - Rate type
  - Rate structure
  Price escalation:
  - DOE energy price projections

NOTES:

Setting the Study Period

Length of Study Period

■ Same time period for
- comparing all alternatives
- calculating economic measures

■ Appropriate time period to
- accommodate investor's time horizon
- take into account expected lives of systems

■ Maximum study period for FEMP projects
- 25 years from beginning of service period

NOTES:

FEMP = Federal Energy Management Program

Sketching Cash Flows

Slide B8

NOTES:

Sketching Cash Flows

Cash Flow Diagram
with phased-in investment costs

Initial Investment   Future Costs

| 1 | 2 | 3 | 4 | 5 | 6 | 7 | / N |

Residual
Value

Base
Date

Planning, Design,
Construction

Service
Date

Occupancy or
System Operation

End of
Study
Period

Study Period
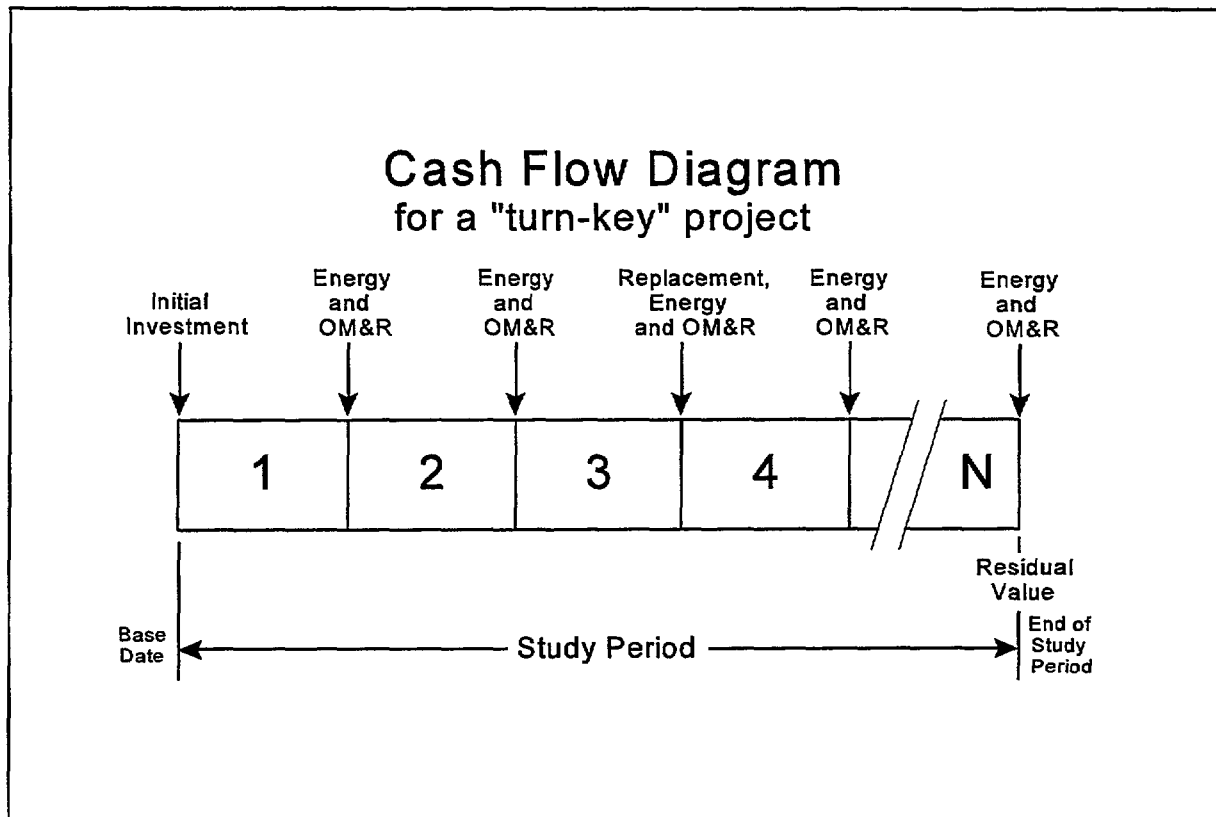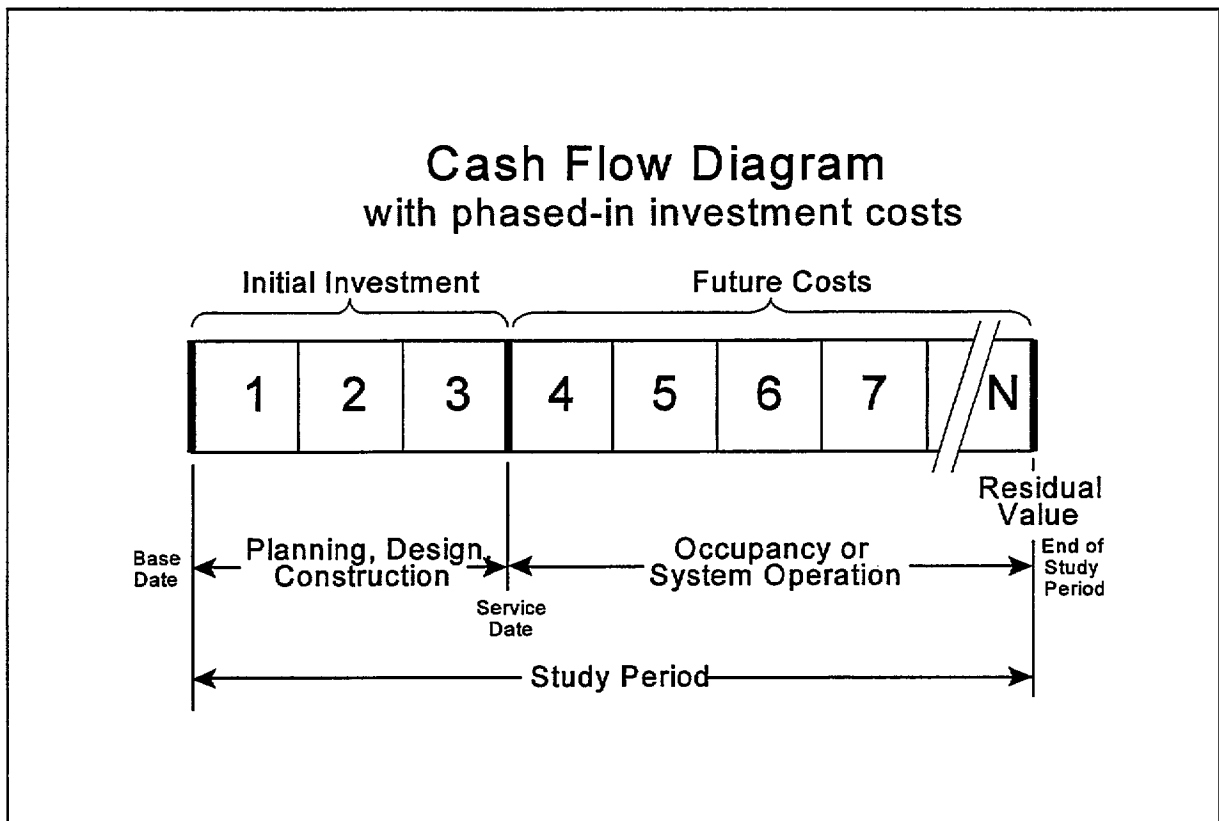
NOTES:

TAKING CARE OF THE PRELIMINARIES

Slide B1

Define the problem and state the objective

The first task is to clearly state what the analyst seeks to investigate and what methods might meet the objective. Specify the design feature or system to be evaluated and determine the kind of decision to be made, i.e., whether it is an accept/reject decision, whether it concerns optimal efficiency levels, system selection, or interdependent systems, or whether it is a budgeting decision. Decide which of the economic measures are the most suitable for the type of decision to be made, i.e., life-cycle costs, net savings, savings-to-investment ratio, adjusted internal rate of return, or discounted payback. Include other relevant information, such as constraints that might limit the number of feasible alternatives.

Decide on the level of effort

Since economic analysis requires time and effort, its scope should be tailored to the needs of the project. The larger the potential savings, the greater the project visibility, the more intense the pressure to decide on the basis of non-economic criteria, the more important it is to have a carefully performed, thoroughly researched, and well documented study. The scope of the analysis might vary from a "back-of-the-envelope" study to a detailed analysis with thoroughly researched input data, supplementary measures of evaluation, complex uncertainty assessment, and extensive documentation.

Choose method of documentation

Carefully document every study, whether small or large, to keep track of the evaluation process, to create a decision-supporting record, and to have a file for future use. Use forms in Handbook 135, computer program output, and your own worksheets and attachments. Include a statement of assumptions made and a narrative describing non-quantifiable costs and benefits.

IDENTIFYING FEASIBLE ALTERNATIVES

Choose alternatives
Slide B2

There are three key points to take into account when choosing alternatives. The most important point is to remember that **your decision can be no better than the best alternative you consider**, no matter how good your economic evaluation.

Second, you need consider only alternatives which **satisfy performance standards**. Also take into account constraints such as availability of energy sources and building code requirements. Do not include in your economic evaluation alternatives that have to be rejected on other grounds.

The third point concerns alternatives that exceed minimum performance requirements, as for example, a reduced noise level. Some organizations specify their performance standards tightly and give no credit to performance in excess of the standards. But others **credit alternatives which exceed minimum performance standards with additional benefits**. If the additional benefit is important to your organization, include it in your calculations if it can be quantified. If it cannot be expressed in dollar amounts, describe the benefit and add the narrative to the documentation package.

SPECIFYING DATA REQUIREMENTS

Relevant effects
Slide B3

To make a decision about economic efficiency, it is important to measure the economic consequences of alternatives. Data requirements for making an economic decision are not the same as those for keeping an accounting system. For an LCC analysis, you need, in general, **evaluate only costs that change** from one alternative to another. Costs that remain the same do not decrease or increase the life-cycle costs of an alternative relative to the base case and thus need not be included.

Because collecting cost data can be expensive, you want to focus on collecting those data which are likely to have a **significant effect** on the life-cycle costs of an alternative. You do not want to spend your limited resources on collecting data that have little impact.

Do not include "sunk" costs in your analysis. Sunk costs are those costs which have already been incurred and cannot be avoided by future decisions. Only amounts that can be changed by the decision need to be included in the analysis.

Typical costs or benefits   Slide B4

Life-cycle costs typically include **investment-related costs** and **operational costs**. Acquisition costs, including costs for planning, design, and construction, are investment-related, as are residual values such as resale value, salvage value, or disposal costs. Under the FEMP rule, capital replacement costs are also defined as investment-related. Energy costs, maintenance costs and repair costs are considered operational costs, that is, non-investment-related costs. This definition is useful when computing economic measures that evaluate long-run savings in operational costs in relation to total capital investment costs.

Some of the costs included in an LCC analysis are **annually recurring**, such as energy, and routine maintenance and repair costs. **Non-annually recurring** costs are those that may occur only one time during the life-cycle, such as acquisition costs and residual values, or several times, such as replacement costs. This definition is needed for choosing the appropriate discount factors used to convert future costs to present values.

In a third classification, acquisition costs are designated as **initial costs** and all other costs as **future costs**, a useful classification both for selecting discount factors and for relating initial investment costs to all other costs of a project.

For some projects, there may be **other** costs or benefits, such as revenue changes, utility rebates, and others.

ESTIMATING CASH FLOWS

Estimate costs in today's prices   Slide B5

The economic evaluation methods--LCC, NS, SIR, AIRR, and PB--require inputs expressed in <u>dollars</u>. Effects not expressed in dollars are not included in the measure of economic performance. But non-quantifiable effects may be of critical importance; they should be described in a narrative so that they will not be overlooked in making a decision.

Because LCC analysis should be performed during the early stages of a project when the potential for cost savings is greatest, cash flows often have to be based on estimates. Reliable estimates can usually be produced from available **historical data, supplier quotes, published estimating guides and databases**, when combined with the experience and skill of the analyst and a sufficient amount of resources spent on data gathering. Do not wait for a detailed take-off of quantities based on engineering specifications to do economic analysis. By then most basic design decisions will have been made and the opportunity to influence the cost consequences of a project will have been greatly diminished.

Initial costs, replacement costs, and residual values

The best source of purchase and installation cost estimates is your local suppliers. Often they also can give some indication of useful lives of materials and equipment, which facilitates estimates on replacement costs and residual values. Combined with engineering experience and judgment, supplier quotes are a reliable source of first cost and related cost estimates.

There are also a number of published printed and computerized sources of data that are useful if supplier quotes are not available. Table B.1 lists some of these estimating guides. Since they all have different emphases and different underlying assumptions, it is recommended that you use the same data set for analyzing all the alternatives for a particular project in order to get consistent and comparable results.

Maintenance and repair costs

One of the more difficult parts of a life-cycle cost analysis is obtaining accurate maintenance and repair estimates. Supplier quotes and published estimating guides sometimes provide relevant information. An extensive database specifically dealing with maintenance and repair estimates is the CERL M&R Database developed by the Army Corps of Engineer's Construction Engineering Research Laboratory. The data are "constructed" data rather than historical data and based on material, equipment, and labor hours required for a particular task. Locality indexes adjust the data for different U.S. regions, and wage and equipment rates are specified by the user. Costs are calculated in present values over a 25-year study period and expressed as dollars per unit as of the date of study. Additional information can be obtained by contacting:

CERL M&R DATABASE
USACE Engineer Division HV
CEHND-ED-ES (Terry Patton)
P.O. Box 1600
Huntsville, AL 35807-5301
(205) 895-3373

Energy costs **Slide B6**

To arrive at the annual dollar value of energy consumed requires three different considerations:

(1) *Btu usage or Btu savings from a project alternative*: Technical specifications may provide information on energy consumption for systems or components. Data on the quantity of energy consumed in a building can come from engineering analysis or from computer programs, such as ASEAM (DOE), DOE-2 (DOE), BLAST (DoD) and ESPRE (EPRI). When selecting a program, it is important to consider whether you need annual, monthly, or hourly energy consumption figures and whether the program adequately tracks savings in energy consumption when design changes or different efficiency levels are simulated. There is no substitute for careful consideration of such estimates by a knowledgeable engineer with practical experience in this field.

(2) *Current energy prices*: It is essential to get current energy prices from local suppliers. It is better not to use regional or national average energy cost data, since they do not reflect local supply and demand conditions. Make sure that the prices take into account, where applicable, the rate type, the rate structure, summer and winter differentials, block rates, and demand charges to obtain an estimate as close as possible to today's actual energy price.

(3) *Energy price projections*: Energy prices are assumed to increase or decrease at a rate different from general price inflation. To avoid inconsistencies in LCC analyses throughout the government, it is required under the FEMP rule (10 CFR 436) to adjust today's energy price estimates by the energy price projections published annually by DOE. These energy price projections are embedded in the discount factors updated annually and published on October 1 of each year in *Energy Prices and Discount Factors for Life-Cycle Cost Analysis 19xx*, Annual Supplement to NBS Handbook 135 and NBS Special Publication 709. These projections are also included in the annual update of the NIST BLCC computer program.

SETTING THE STUDY PERIOD

Slide B7

The study period is the time over which the effects of a decision are of interest to the decision maker. There is no one correct study period, but it must be sufficiently long to enable a correct assessment of long-run economic performance. Often the life of the system under analysis is used as the study period. However, the Federal Government limits the study period to a maximum of 25 years from the service date. Apart from the 25-year maximum limit, there are other factors that determine the length of the study period:

(1) **Compare all alternatives over the same study period.** Present-value cash flows calculated for one time period would not be comparable with those calculated for a longer or shorter period.

(2) **Calculate all measures of economic evaluation (LCC, NS, SIR, AIRR) using the same study period,** otherwise they would not be consistent with each other.

(3) **Consider the time horizon of the investor.** The study period may be shorter or longer depending on whether the investor is, for example, the builder or the occupant of a building.

(4) **Adjust for different expected lives of buildings or systems.** In order to fit different expected lives into the same study period, equalize the differing time periods by using replacement values and residual values, such as a resale value, salvage value, or disposal costs.

SKETCHING CASH FLOWS

Cash-flow diagrams   **Slides B8 & B9**

It is often useful to draw a simple cash-flow diagram to show the type and timing of costs that were identified for the project. Key dates can be entered to indicate, for example, the base date, the service date, the end of the analysis period. The cash-flow diagram provides a visual checklist of relevant effects and their timing.

Under the FEMP rule, initial investment costs can be assumed to occur in a lump sum on the service date, that is when the building is occupied or the system taken into operation and when energy costs and other operational costs begin to accrue. In general this assumption of a **"turn-key" project** is accurate enough, but when these initial investment costs occur over more than one year the analyst may want **to phase in initial investment costs over a planning/construction period**. The study period can exceed the FEMP-mandated maxim 25-year limit by the length of the planning/construction period.

Cash-flow modeling

It is common practice in economics to model cash amounts, which occur at varying times within the year, as if they occurred either at the beginning of the year, middle of the year, end of the year, or continuously throughout the year, rather than exactly as each amount is actually paid. Dollar amounts that are more or less repeating are typically modeled as a uniformly recurring series. The effort to describe exactly the timing of costs and benefits is generally not worthwhile. Complex flows of costs and benefits can be represented in a simple form without sacrificing accuracy. In general, when using manual LCC calculation methods (including look-up tables) it is preferable to assume that initial capital investments be discounted from the beginning of the year in which they are incurred, and all other costs be discounted from the end of the year in which they are incurred. With computer modules which allow the user to specify more analytical detail, it is preferable to discount all one-time costs from the actual time of occurance and to discount annually recurring costs from the middle of the year.

EXERCISE B1
Relevant Effects

Suppose you want to evaluate whether it is cost effective to replace an existing HVAC system with a new system. Assume that the existing system can continue to meet heating and cooling requirements over the remaining 10 years that the owner plans to occupy and own the building. From the following list, check the data you need:

1.	Original land costs	$100,000
2.	Original site improvements	$50,000
3.	Initial construction costs	$500,000
4.	Purchase and installation costs of the existing HVAC system	$10,000
5.	Duct work for the existing HVAC system	$10,000
6.	Modification of the existing duct work to meet requirements of the new HVAC system	$2,000
7.	Purchase and installation costs of the new HVAC system	$50,000
8.	Maintenance cost of the existing HVAC	$2,000/year
9.	Maintenance cost of the new HVAC	$2,000/year
10.	Heating efficiency/cooling COP of existing system	0.65/2.0
11.	Heating efficiency/cooling COP of new system	0.80/3.0
12.	Current price of energy used by the existing system (oil)	$1.25/gallon
13.	Current price of energy used by the new system (natural gas)	$0.70/therm
14.	Projected rate of change in price of energy used by existing system	7%/year
15.	Projected rate of change in price of energy used by new system	5%/year
16.	Building heating load (annual)	3,000 MBtu
17.	Building cooling load (annual)	4,000 MBtu
18.	Existing HVAC system's current resale, less removal costs	$5,000
19.	New HVAC system's resale, less removal costs, at the end of its 30-year service life	$10,000
20.	Replacement costs of existing system at the end of its 15-year remaining service	$35,000
21.	Replacement of new system at the end of its 30-year service life	$45,000
22.	The amount the new system will add to resale value of the building in 10 years	$10,000
23.	The new system operates more quietly than the existing system	

EXERCISE B2
Setting the Study Period

Choose a study period for each of the following situations:

1. A building owner wants to evaluate the cost effectiveness of an automatic thermostat control which will last 15 years. The building will be used indefinitely.

2. A designer wishes to perform an LCC comparison of two solar window films. Film A lasts five years; film B lasts 10 years. The building will be used indefinitely.

3. The FEMP rule sets a limit of 25 years on LCC studies of energy conservation projects in federal facilities. An analyst is evaluating alternative roof insulation systems for a federal building, one of which lasts 15 years and one of which lasts 30 years.

ADJUSTING CASH AMOUNTS TO PRESENT VALUE

MODULE C   Lecture, Discussion, Exercises

Objectives

At the conclusion of this session, you will be able to

- Understand the concept of discounting cash flows to present value

- Find correct present-value factors for different applications

- Choose the correct method for handling inflation in an LCC analysis

Discounting Future Amounts
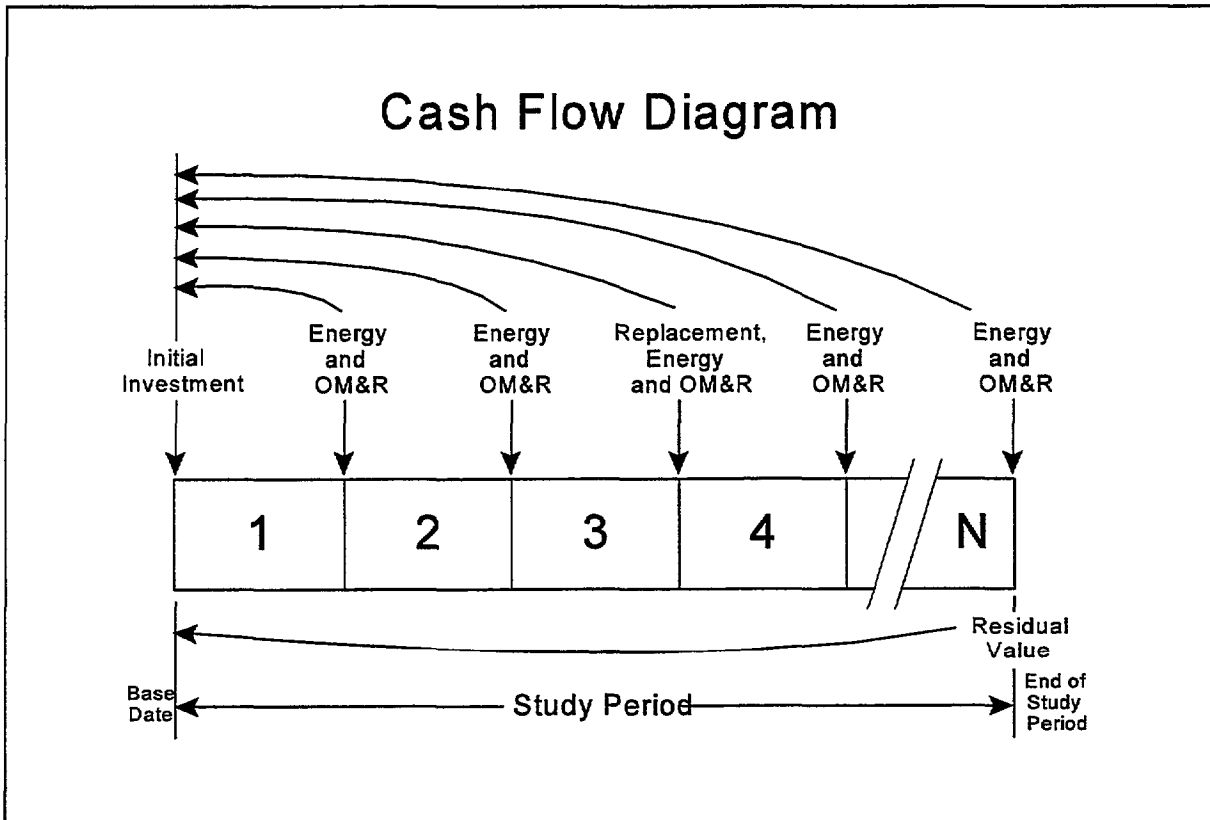
Slide C1

NOTES:

Discounting Future Amounts   Slide C2

Discount Rate

The rate of interest which makes an investor
indifferent between cash amounts received
at different points in time.

NOTES:

Discounting Future Amounts

Discount Rate Calculation Given Present Value and Future Amount

$$d = \left[\frac{Ft}{PV}\right]^{1/t} - 1$$

Example:

one year: $d = \left[\dfrac{\$108}{\$100}\right]^{1/1} - 1 = 0.08 = 8\%$

ten years: $d = \left[\dfrac{\$200}{\$100}\right]^{1/10} - 1 = 0.0718 = 7.18\%$

NOTES:

d	=	discount rate
F_t	=	future amount in year t
PV	=	present value

Discounting Future Amounts

Future Value of Present Amount

$$F_t = P \times (1 + d)^t$$

Example: $F_{10} = \$100 \times (1 + 0.08)^{10} = \$100 \times 2.16 = \$216$

**Single Compound
Amount Factor
(SCA)**

NOTES:

F_t	=	future value in year t
P	=	present amount
d	=	discount rate

Discounting Future Amounts

Slide C5

Present Value of Future Amount in Year t

$$PV = F_t \times \frac{1}{(1 + d)^t}$$

example: $PV = \$216 \times \frac{1}{(1 + 0.08)^{10}} = \$216 \times 0.4632 = \$100$

**Single Present
Value Factor
(SPV)**

NOTES:

Discounting Future Amounts

Present Value of Annually Recurring Uniform Amounts Over n Years

$$PV = A_0 \times \frac{1}{(1+d)^1} + A_0 \times \frac{1}{(1+d)^2} + A_0 \times \frac{1}{(1+d)^3} + \ldots + A_0 \times \frac{1}{(1+d)^n}$$

$$PV = A_0 \times \sum_{t=1}^{n} \frac{1}{(1+d)^t} = A_0 \times \frac{(1+d)^n - 1}{d(1+d)^n}$$

Example:

$$PV = \$100 \times \frac{(1.08)^{10} - 1}{0.08(1.08)^{10}} = \$100 \times 6.710 = \$671$$

Uniform Present
Value
(UPV)

NOTES:

A_0 = annual amount at base-year price (year = 0)

Discounting Future Amounts   Slide C7

Present Value of Annually Recurring Non-Uniform Amounts Over n Years

$$PV = \frac{A_1}{(1 + d)^1} + \frac{A_2}{(1 + d)^2} + \frac{A_3}{(1 + d)^3} + \ldots + \frac{A_n}{(1 + d)^n}$$

$$PV = A_0 \times \frac{(1 + e)^1}{(1 + d)^1} + A_0 \times \frac{(1 + e)^2}{(1 + d)^2} + A_0 \times \frac{(1 + e)^3}{(1 + d)^3} + \ldots + A_0 \times \frac{(1 + e)^n}{(1 + d)^n}$$

$$PV = A_0 \times \sum_{t=1}^{n} \left[\frac{1 + e}{1 + d}\right]^t = A_0 \times \frac{(1 + e)}{(d - e)} \left[1 - \left[\frac{1 + e}{1 + d}\right]^n\right]$$

Example:

$$PV = \$100 \times \frac{1.03}{(0.08 - 0.03)} \left[1 - \left[\frac{1.03}{1.08}\right]^n\right] = \$100 \times 7.777 = \$778$$

**Modified Uniform
Present Worth Factor
(UPW*)**

NOTES:

$e \quad = \quad$ differential rate of energy price escalation

Discounting Future Amounts

PV of Annual Energy Costs

■ Use DOE projections of energy price escalation rates

■ DOE energy price escalation rates vary

-by region:　1 = Northeast
　　　　　　　2 = Midwest
　　　　　　　3 = South
　　　　　　　4 = West

- by fuel type:　Electricity　　LPG
　　　　　　　　Fuel Oil　　　Coal
　　　　　　　　Natural Gas

- by rate type:　Residential
　　　　　　　　Commercial
　　　　　　　　Industrial

- by year

■ Annual Supplement to Handbook 135 (Tables B-1a through B-5a) provides current UPV* factors

---

NOTES:

Discounting Future Amounts

PV of Annually Recurring Energy Costs with DOE Energy Price Escalation Rates

Example (1996):

Annual electricity cost at current prices = $1,000
Region: 1
Fuel Type: electricity
Rate Type: residential
Number of Years: 25
Discount Rate: 4.1%
UPV* Factor: 16.35

PV = Annual electricity cost x UPV*
PV = $1,000 x 16.35 = $16,350

NOTES:

Discounting Future Amounts

Summary of Present Value Factors

<u>Amount to be Discounted</u>   <u>Formula</u>

Single future amount (year t) $PV = F_t \times SPV_{(t,d)}$

Recurring annual amount (over n years) $PV = A_0 \times UPV_{(n,d)}$

Changing annual amount (over n years) $PV = A_0 \times UPV^*_{(n,d,e)}$

NOTES:
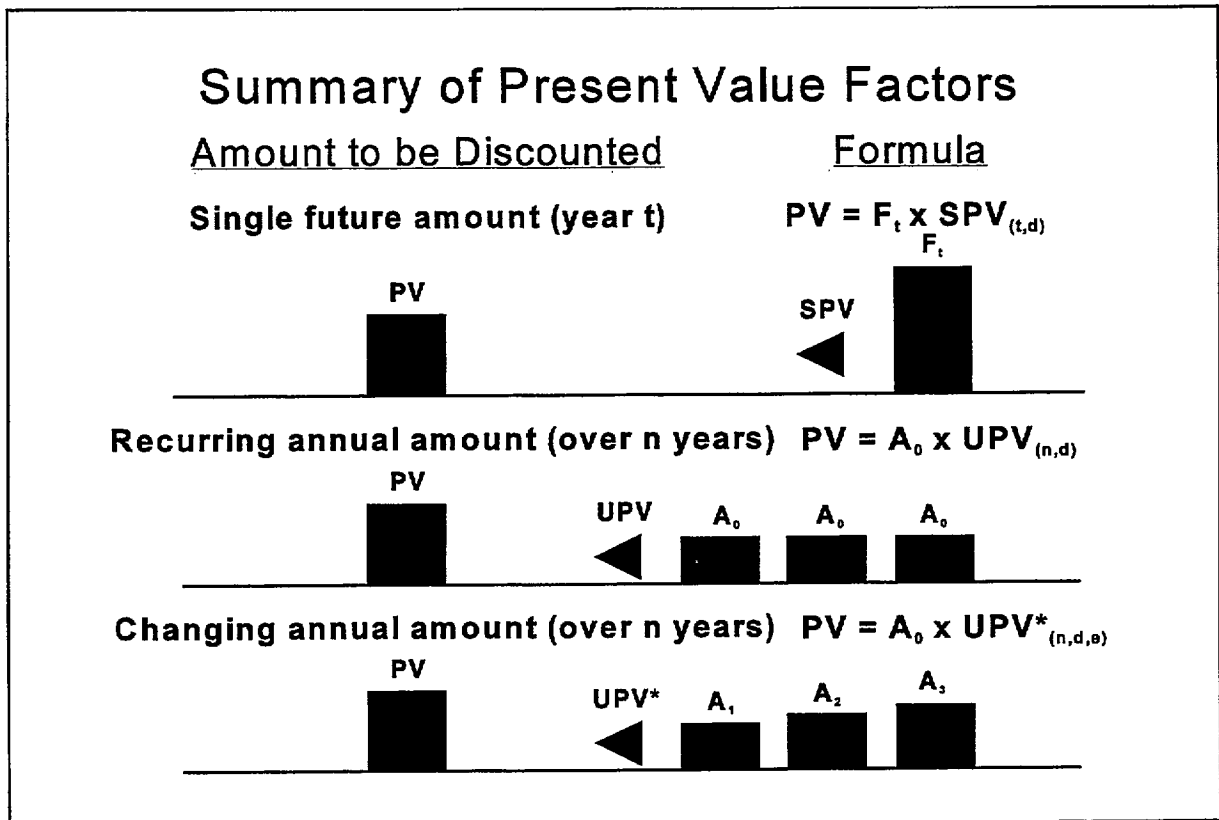
Discounting Future Amounts

Discounting
Comparison of Rates
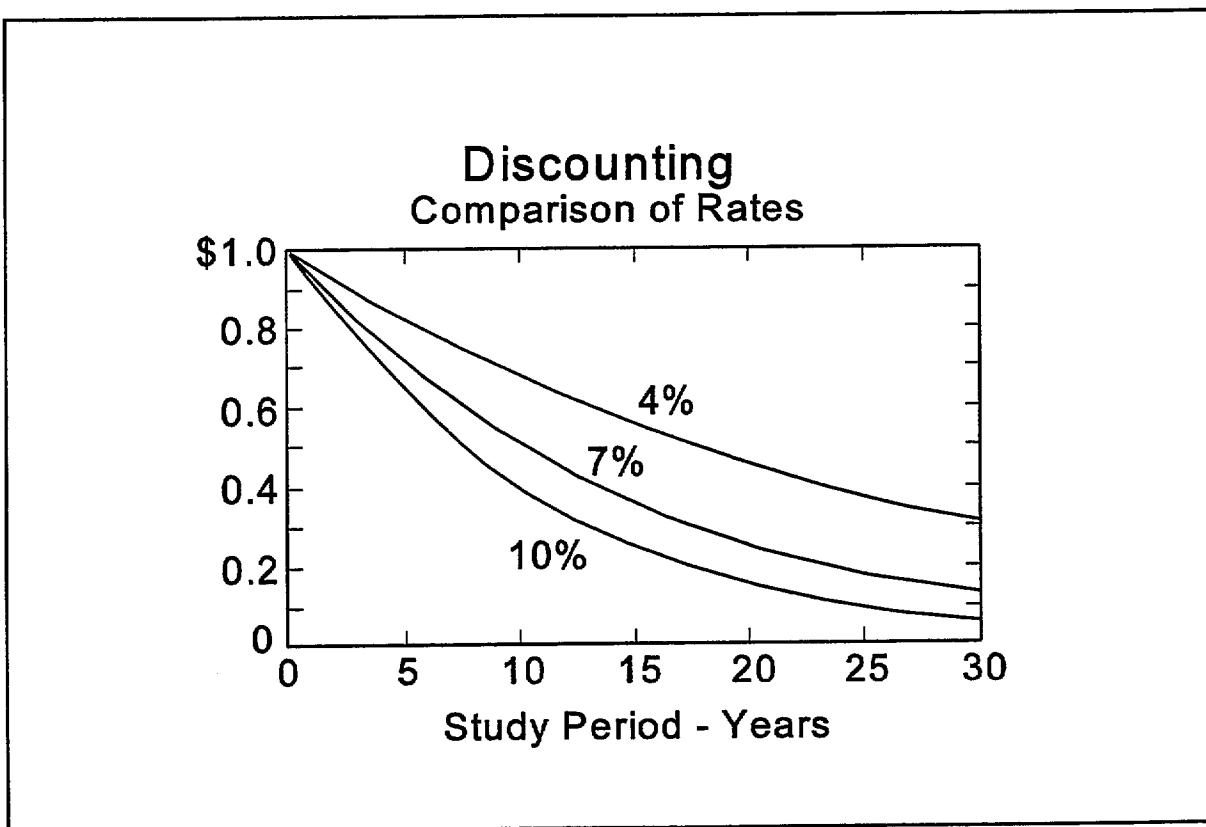
NOTES:

Discounting Future Amounts   Slide C12

Discounting Example

Find present value (PV) of a future
replacement cost (F$_t$)

- Replacement cost: $10,000
- Time of replacement: end of year 6
- Discount rate: 4%

NOTES:

Discounting Future Amounts

Solution:

$$PV = F_t \times SPV$$

$$= \underline{\qquad} X \underline{\qquad}$$

$$= \$ \underline{\qquad}$$

NOTES:

Discounting Future Amounts   Slide C14

Discounting Example

Find present value (PV) of an annually
recurring maintenance cost (A_o)

- Annual maintenance cost: $200
- Occurrence: end of each of 12 years
- Discount rate: 9%

NOTES:

Discounting Future Amounts

Solution:

$$PV = A_0 \times UPV$$

$$= \underline{\qquad} \times \underline{\qquad}$$

$$= \$ \underline{\qquad}$$

NOTES:

Discounting Future Amounts

Discounting Example

Find present value (PV) of energy costs which
are changing at a constant rate

- Annual energy cost at today's price (A_0) : $25,000
- Occurrence: end of years 1-7
- Discount rate: 6%
- Projected annual rate of energy price
  escalation: 2%

NOTES:

Discounting Future Amounts

Slide C17

Solution:

$PV = A_0 \times UPV^*$

$= \underline{\hspace{1cm}} \times \underline{\hspace{1cm}}$

$= \$ \underline{\hspace{2cm}}$

NOTES:

Discounting Future Amounts

Discounting Example

Find present value (PV) of energy costs which
are changing at annual rates projected by DOE

- Annual energy cost at today's price
  (A_0): $50,000
- Occurrence: beginning 1996 and
  continuing over 25 years
- Building location: Federal office building
  in Atlanta
- Fuel type: natural gas
- Rate type: commercial
- DOE 1996 energy price projections

NOTES:

Discounting Future Amounts

Solution:

$$PV = A_0 \times UPV*$$

$$= \underline{\hspace{2cm}} X \underline{\hspace{2cm}}$$

$$= \$ \underline{\hspace{2cm}}$$

NOTES:

How to Handle Inflation

Purchasing Power of the Dollar
1970 - 1992

NOTES:

How to Handle Inflation

Definitions

- Inflation: the rate of increase in the general level of prices

- Price Escalation: the rate of increase in the price of a particular commodity (e.g., electricity prices)

- Differential (real) price escalation: the rate of increase in the price of a particular commodity relavtive to inflation

NOTES:

How to Handle Inflation

Slide C22

Definitions

- Constant dollars: dollars of uniform purchasing power, exclusive of general inflation

- Current dollars: dollars of purchasing power in which actual prices are stated, inclusive of general inflation

---

NOTES:

How to Handle Inflation

Rate of Change in Price of Home - Related Items Compared with All Items

NOTES:

How to Handle Inflation

Two Approaches for Dealing with Inflation

1. Include general price inflation:
   - Specify all costs in current dollars
   - Use a "nominal" discount rate (including inflation)
   - Use "nominal" escalation rates

2. Exclude general price inflation:
   - Specify all costs in constant dollars
   - Use a "real" discount rate (excluding inflation)
   - Use "real" escalation rates

Both approaches yield the same present values
if calculated correctly

NOTES:

How to Handle Inflation

Derivation of the real discount rate (d)
given the nominal discount rate (D),
and the rate of inflation (I):

$$d = \frac{1 + D}{1 + I} - 1 \qquad D = (1 + I)(1 + d) - 1$$

Example: D = 8%, I = 4%

$$d = \frac{1.08}{1.04} - 1 = 0.03846 = 3.846\%$$

NOTES:

How to Handle Inflation

Present value of one-time cost in year t

1. Current dollars with nominal discount rate:

$$PV = C_t \times \frac{1}{(1 + D)^t}$$

2. Constant dollars with real discount rate:

$$PV = C_0 \times \frac{1}{(1 + d)^t}$$

NOTES:

C_t = current cost in year t
C_0 = currrent cost in base year

How to Handle Inflation

Estimating a future cost in year t given today's cost:

Current dollars (E = nominal escalation rate)

$$C_t = C_0 \times (1 + E)^t$$

Constant dollars (e = real escalation rate)

$$C_t = C_0 \times (1 + e)^t$$

NOTES: C_0 is the price as of the base year, C_t is the price at the end of year t.

How to Handle Inflation

Present value analysis including price escalation:

1. Current dollars with nominal discount rate:

$$PV = C_0 \times \left[\frac{1 + E}{1 + D} \right]^t$$

2. Constant dollars with real discount rate:

$$PV = C_0 \times \left[\frac{1 + e}{1 + d} \right]^t$$

NOTES:

How to Handle Inflation

Derivation of the real (differential) escalation rate (e) given the nominal escalation rate (E) and the rate of inflation (I):

$$e = \frac{1 + E}{1 + I} - 1 \qquad E = (1 + I)(1 + e) - 1$$

Example: E = 6%,   I = 4%

$$e = \frac{1.06}{1.04} - 1 = 0.01923 = 1.923\%$$

NOTES:

How to Handle Inflation
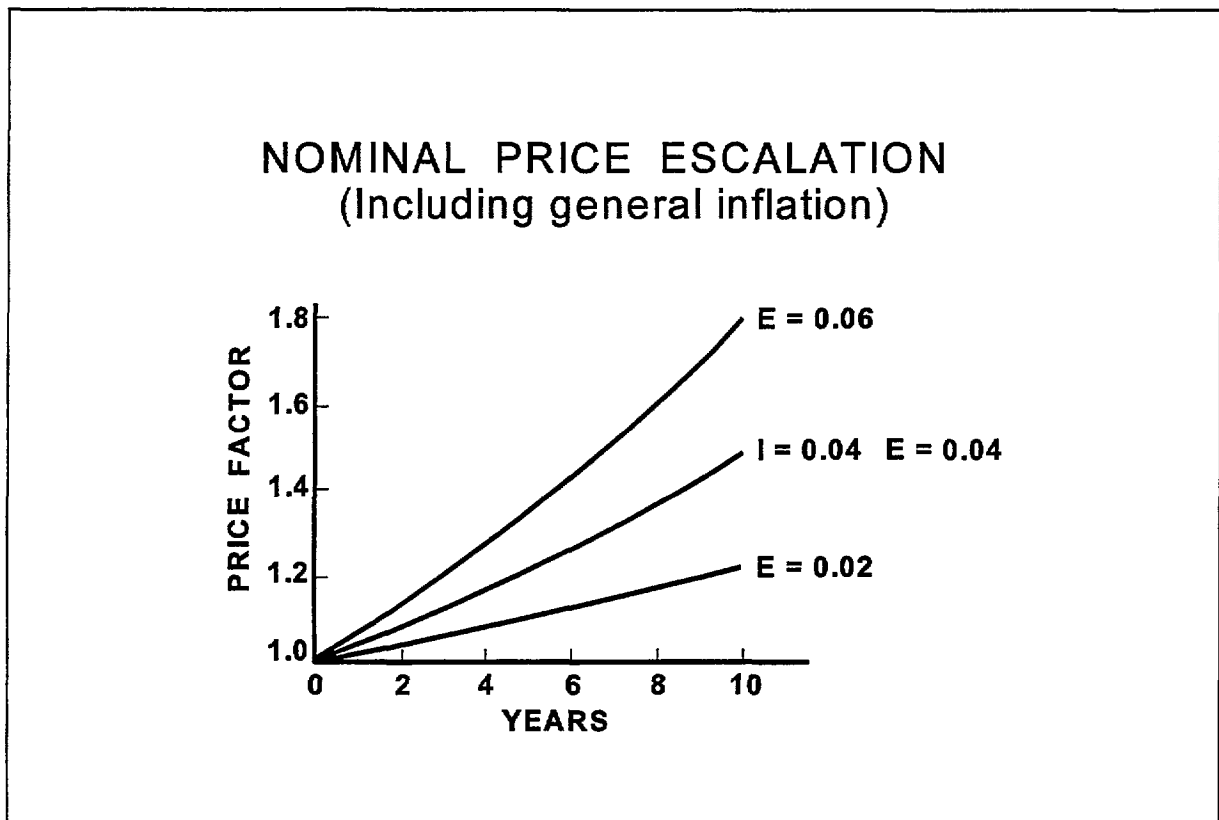
NOTES:

How to Handle Inflation

REAL PRICE ESCALATION
(Excluding general inflation)

$$e = 0.0192 \quad \left(\frac{1.06}{1.04} - 1\right)$$

$$e = 0 \quad \left(\frac{1.04}{1.04} - 1\right)$$

$$e = -0.0192 \quad \left(\frac{1.02}{1.04} - 1\right)$$

PRICE FACTOR

1.2

1.0

0.8

YEARS: 0 2 4 6 8 10
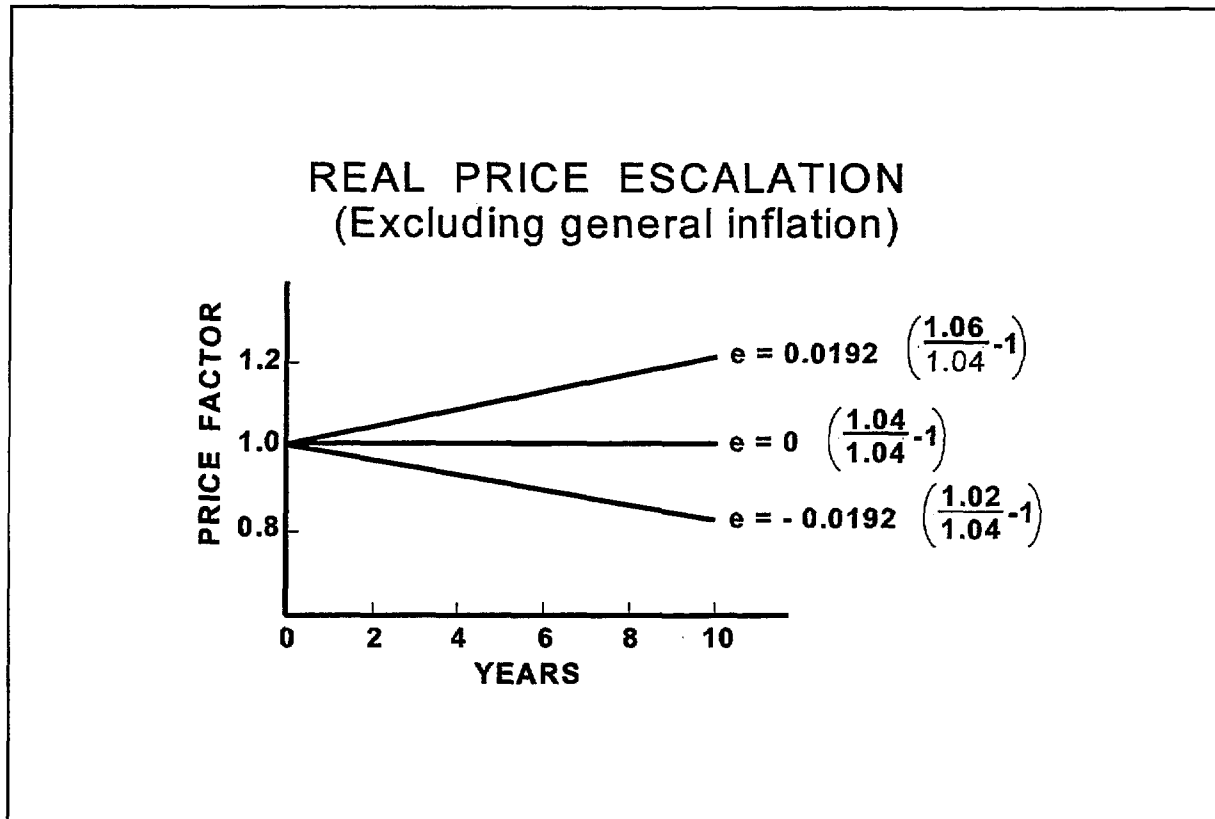
NOTES:

How to Handle Inflation

Present value of one-time cost occurring in year t, C_t:

Using nominal rates:

$$PV = C_0 \times \left[\frac{1 + E}{1 + D}\right]^t \qquad \$100 \times \left[\frac{1.06}{1.08}\right]^{10} = \$82.95$$

$$PV = C_0 \times \left[\frac{(1 + I)(1 + e)}{(1 + I)(1 + d)}\right]^t$$

Using real rates:

$$PV = C_0 \times \left[\frac{1 + e}{1 + d}\right]^t \qquad \$100 \times \left[\frac{1.01923}{1.03846}\right]^{10} = \$82.95$$

NOTES:

DISCOUNTING FUTURE COSTS TO PRESENT VALUE

Definition   Slide C1

Before we can compare or sum costs occurring at different points over the study period, they must be converted to a common point in time to reflect the time value of money. This conversion process is called **discounting**. Usually future costs (or savings) are **discounted to present value** so that they can be directly compared with initial investment costs.

Cash-flow conventions

There are several **cash-flow conventions** that may be used when discounting costs occurring over the study period to present value. One-time costs are usually discounted from the actual time of occurrence. Annually recurring costs (costs which occur every year in approximately the same amount) are usually discounted from the end of the year (although mid-year or beginning-of-year methods are acceptable if used consistently). Costs which occur at the beginning of the study period do not need to be discounted since they are already in present value.

Discount rate   Slides C2 and C3

The **discount rate** used to adjust future costs to present value is the rate of interest which makes the investor indifferent between cash amounts received at different points in time. Thus if you are just as satisfied with receiving $110 a year from now as receiving $100 today (but would not find $109 acceptable), your discount rate would be 10 percent. The mathematics of discounting are identical with the mathematics of compound interest which are used every day by financial analysts. The discount rate reflects the investor's time value of money, that is, the rate of return from the best alternative investment foregone. This rate is often referred to as the **minimum acceptable rate of return** (MARR). It is important to recognize that every investor has his or her own time preference for money, and thus his or her own discount rate.

If we know the future amount that is considered to be equivalent to a present amount from an investor's standpoint, we can calculate the discount rate by taking the nth root[1] of the ratio of future amount to present amount and subtracting 1. Thus, if an investor is indifferent between $108 received a year from now and $100 received today, the corresponding discount rate is 8 percent; for $200 received in 10 years and $100 today the corresponding discount rate is 7.18 percent.

---

[1]To take the nth root of x, raise x to the 1/n power using a hand calculator with a x^y function, where y is the power of x.

Discount calculations and discount factors

Slides C4 and C5

We can calculate the **future value** of a present amount, or the **present value** of a future amount, if we know the discount rate. The formulas shown in these two slides are standard compound interest formulas, used with discount rates rather than interest rates. That is, they are not used to compute obligated principal and interest payments but rather to compute amounts which can be considered to be time-equivalent from an investment standpoint.

An easier method of computing present values and future values is to look up the appropriate discount factor in a standard table of discount factors. NIST publication *Discount Factor Tables for Life-Cycle Cost Analyses* (NISTIR 89-4203) is a good source for such discount factors.

Discount factors for one-time amounts

In slide C4, the equation term in parentheses produces the **Single Compound Amount (SCA)** factor which, when multiplied by the present amount, gives the future value of that amount. In slide C5, the equation term in parentheses produces the **Single Present Value (SPV)** factor, which, when multiplied by the future amount, gives the present value of that amount.

Discount factors for annually recurring uniform amounts

Slide C6

This slide shows how to compute the present value of a series of cash amounts that occur annually over a given study period and are the same each year. The first equation shows the cash amount in each year discounted individually and all of the resulting present values summed to arrive at a present value for the entire stream of costs. By rearranging the terms you arrive at the closed-form equation whose bracketed part produces the **Uniform Present Value (UPV)** factor. This UPV factor is multiplied by the uniform annual amount to get the present value of the entire stream of cash flows. UPV factors can also be found in most tables of discount factors, including NISTIR 89-4203.

Discount factors for annually recurring non-uniform amounts

Slide C7

Sometimes recurring annual amounts are not uniform, but change from year to year at some known annual rate (e). This rate of change can be either positive or negative, but usually reflects price increases over time. Again, the present value can be computed for the cash amount in each year and summed, or a closed-form equation can be used to calculate the present value. The factor produced by this equation is called the **Modified Uniform Present Value (UPV*)** factor, which can be multiplied by the base annual amount (the annual amount as of the beginning of the study period) to get the present value of the entire stream of cash flows. UPV* factors that change by some percentage each year can be found in NISTIR 89-4203.

UPV* factors for energy costs

For LCC analyses related to energy conservation in federal facilities, NIST publishes UPV* factors specifically for use with future energy costs. The NIST UPV* factors explicitly incorporate the FEMP discount rate and DOE projections of energy price increases over the next 30 to 40 years. They are published in NISTIR 85-3273, *Energy Price Indices and Discount Factors for Life-Cycle Cost Analysis 19xx*, tables B-1a through B-5a. Because the FEMP discount rate and the DOE projections of energy price escalation rates change from year to year, this publication is updated by NIST each year on October 1. Always use the edition for the current fiscal year when performing LCC analyses of energy conservation and renewable resource investments for the Federal Government. Note that the UPV* factors in this publication are differentiated by fuel type, rate type (residential, commercial, industrial), and by region (Northeast, Midwest, South, and West). The UPV* factor for energy costs is used with the annual energy cost computed in base-year dollars, i.e., with energy prices as of the beginning of the study period. (For LCC studies in DoD, a separate NIST publication is used, NISTIR 4942, *Present Worth Factors for Life-Cycle Cost Studies in the Department of Defense (19xx)*.)

Summary of common discounting applications

When performing an LCC analysis, three types of future cash flows are most commonly encountered, each having a different type of present-value factor:

(1) The **one-time cash flow** is multiplied by the **Single Present Value (SPV)** factor to find its present value. An example of a one-time cash flow is a replacement cost or a residual value at the end of the study period.

(2) The **uniform annual amount** is multiplied by the **Uniform Present Value (UPV)** factor to find the present value. An example of a uniform annual amount is an annual operating and maintenance cost.

(3) The **changing annual amount** changes from year to year at some known rate; the base-year amount (A_0) is multiplied by the **Modified Uniform Present Value (UPV*)** factor to find the present value. An example of a changing annual amount is the annual energy cost of a building when the physical amount of energy consumed is expected to be reasonably constant but energy prices are expected to change from year to year.

Sensitivity of present value to discount rate

The present value of a future amount is sensitive to both the discount rate and the number of years over which the future amount is discounted. Note that the present value of a future amount calculated using a 4 percent discount rate is significantly greater than the present value for a 7 or 10 percent discount rate after just a few years. This means that energy-saving projects evaluated with a lower discount rate show higher present-value savings than projects evaluated with a higher discount rate.

For many years, the Office of Management and Budget (OMB) required the use of a 10 percent real discount rate to discount future savings from capital investments made by the Federal Government.

The National Energy Security Act mandated in 1980 the use of a 7 percent real discount rate for energy conservation and renewable resource investments made by the Federal Government. In 1990 DOE began requiring the use of a discount rate based on federal long-term bond yields. In 1992 OMB began requiring the use of a similarly derived discount rate (based on federal long-term bond yields) for capital investments in government facilities intended to reduce future operating-related costs other than energy costs.

Discounting examples   Slides C12 - C19

The first three examples use discount factors which are taken from NISTIR 89-4203, *Discount Factor Tables for LCC Analyses*. The last example uses a discount factor from NISTIR 85-3273-X, *Energy Price Indices and Discount Factors for Life-Cycle Cost Analysis 19XX*.

HOW TO HANDLE INFLATION

The purchasing power of the dollar   Slide C20

Inflation reduces the purchasing power of the dollar over time. Dollars expended in different years, with different purchasing power, cannot be added together directly to arrive at a meaningful amount. In economic evaluations of capital investments over time, both the changing purchasing power of the dollar as well as the time value of money (as reflected in the discount rate) must be considered in the analysis.

Definitions   Slides C21 and C22

Five terms are defined in these two slides: **price inflation, price escalation, differential escalation, constant dollars**, and **current dollars**. These terms will be used frequently in the following discussion on handling inflation in an economic analysis of capital investments.

Changes in price levels   Slide C23

The solid line on this graph shows the annual rate of general inflation since 1967. Escalation rates for certain cost categories related to buildings are also shown. Energy prices are a type of cost that has deviated significantly from general inflation since the early 1970s. For this reason, the FEMP LCC methodology for evaluating energy conservation investments requires that projected increases in energy prices be explicitly included in the economic analysis, while other categories of costs are generally assumed to increase at the rate of general inflation.

Constant dollars versus current dollars   Slide C24

There are **two basic approaches for dealing with inflation** in an economic analysis. The first approach uses **current dollars and a "nominal" discount rate**. If this approach is used, then price escalation rates used to convert base-year costs to future amounts **must include general inflation**. This is the approach that is generally used when tax considerations are included in the economic analysis, because income taxes are not indexed for inflation. The second approach uses **constant dollars with a "real" discount rate**, i.e., a discount rate **net of general inflation**. In this case only **differential** price escalation rates are included in the analysis, exclusive of general inflation.

Constant-dollar analyses are generally used in government studies where income taxes are not a consideration.

Both constant- and current-dollar analyses, if conducted properly, will yield exactly the same present-value result, and thus support the same conclusion. However, it is generally easier to conduct an economic analysis in constant dollars because the underlying rate of inflation from year to year over the study period does not need to be estimated.

It is important to differentiate between a **present-value analysis** of a capital investment and a **budget analysis**, where funds must be appropriated for year-to-year disbursement. The purpose of a present-value analysis is to determine whether the overall savings appear to justify the required investment at the time that the investment decision is being made. A budget analysis must include general inflation to assure that sufficient funding will be appropriated in future years to cover actual expenses.

Derivation of real discount rate   Slides C25 and C26

The **real discount rate (d)** can be derived from a **nominal discount rate (D)** if the underlying rate of inflation (I) is known. It is important to recognize that d is not found by simply subtracting the inflation rate from the nominal discount rate. The illustrated derivation of d is essential if the present-value analysis is to be the same whether it is conducted in constant or in current dollars.

The present value of a future amount can be found using either the future amount itself with a nominal discount rate (D) or using the base-year amount with a real discount rate (d).

Estimating future costs given today's costs   Slide C27

Future costs can be expressed in current dollar terms (with inflation) or in constant dollar terms (net of inflation). If you are using **current dollars** in your LCC analysis, the **nominal** price escalation rate (E) for the commodity must be used to convert today's cost (C_o) to its future equivalent cost. If you are using **constant dollars** in your LCC analysis, the **real** price escalation rate (e) for the commodity must be used to convert today's cost to its future equivalent cost. In the LCC methodology presented in this workshop, the adjustment of today's costs to a future cost is usually performed at the same time as the discounting operation, as shown in the next slide. However, it is helpful to understand how future costs can be computed, given today's cost, an escalation rate, and the future point in time. (Note that these equations treat the price escalation rate as constant from year to year. If the rate changes from year to year, the future cost must be computed by compounding the amount ($1 + E_i$) for each year, i = 1 to t, where E_i is the escalation rate in year i. This is how the FEMP UPV* factors for energy use are calculated, since the DOE price escalation rates vary from year to year.)

Present values of future costs with escalation   Slide C28

The future amount can always be calculated from the **base-year cost (C_0)**, which is the cost that we generally know best and the cost that we start with in the FEMP LCC methodology. We can use the base-year cost regardless of whether we use real or nominal escalation rates.

The present-value results are identical whether

> the base-year cost is **escalated to its future amount using a nominal price escalation rate (E,** including inflation) and **discounted back to present value using a nominal discount rate (D),** or whether

> the base-year cost is **escalated to its future amount in constant dollars using a real escalation rate (e,** the differential escalation rate) and **discounted back to present value using a real discount rate (d).**

Both methods give the same result if properly computed.

Derivation of real escalation rate   Slide C29

The real escalation rate (e) can be derived from the nominal escalation rate (E), given the underlying general inflation rate (I). Note the similarity in relationships between discount and escalation rates:

Relationships of **real** and **nominal** rates:

$$d = (1 + D)/(1 + I) - 1$$
$$D = (1 + d)(1 + I) - 1$$

$$e = (1 + E)/(1 + I) - 1$$
$$E = (1 + e)(1 + I) - 1$$

where d = real discount rate, excluding inflation
         D = nominal discount rate, including inflation
         e = real rate of escalation, excluding inflation
         E = nominal rate of escalation, including inflation

General inflation and price escalation rates   Slides C30 and C31

The graphs shown in slides C30 and C31 help to illustrate the relationship between **real** and **nominal** prices over time. They show how the price factor for a particular commodity (the ratio of its future price to its base year price) at a given point in time relates to the inflation rate and the price escalation rate. The first graph shows this relationship in nominal terms (including general inflation). The second graph shows this relationship in real terms (net of general inflation). Note that these graphs only show the conversion of today's prices to future prices; they do not include the effects of discounting.

The graph in slide C30 shows the compounding effects of inflation (I) and nominal price escalation (E) over a 10 year period. The vertical axis shows the price factors corresponding to an inflation rate (4 percent here) and to two nominal price escalation rates (2 percent and 6 percent). These are the price factors that you would use if you want to estimate actual prices in future years, given today's price and these rates. For example, if **nominal price escalation** for a particular commodity is 2 percent per year when the general inflation rate is 4 percent, the actual price of that commodity in

future years will be 1.22 (i.e., 1.02^{10}) times its base-year price, more than its price in the base year but less than it would be if it increased in price at the general inflation rate of 4 percent, with a price factor of 1.48 (1.04^{10}).

The graph in slide C31 shows the corresponding price factors in **real** terms, i.e., net of general inflation. These are the factors that you would use if you want to estimate future costs in base-year constant dollars. Regardless of the general inflation rate, if the price of a particular commodity increases at exactly the same rate as general inflation, the real escalation rate is 0 percent, and the price factor for that commodity is 1.0 in all years. The nominal price escalation rate of 2 percent shown in the previous graph is equivalent to a real escalation rate of -1.92 percent (1.02/1.04 -1). At this rate, the price factor decreases over time, from 1.0 at the beginning of the base year to 0.82 at the end of year 10 (0.98077^{10}). That is, the real price of the commodity at the end of the tenth year will be 82 percent of its base price. The nominal escalation rate of 6 percent used in the previous graph is equivalent to a real escalation rate of +1.92 percent (1.06/1.04 -1). At this rate, the price factor increases over time, from 1.0 at the beginning of the base year to 1.21 at the end of year 10 (1.01923^{10}).

Example   Slide C32

The present value is identical for both methods of handling inflation: the first using a nominal escalation rate and a nominal discount rate, the second using a real escalation and a real discount rate. In the first example, the nominal escalation rate and discount rates are 6 percent and 8 percent. In the second example, the nominal rates have been adjusted to their real equivalent values using a 4 percent general inflation rate.

In conclusion, whether you include inflation or not in your LCC analysis, you get the same present-value amounts, if you perform the calculations correctly. Comparing the same present-value amounts, you come to the same conclusion as to whether a project is cost effective or not on a life-cycle cost basis. But be careful. Do not use a real discount rate with a nominal price escalation rate, or vice versa.

EXERCISE C1
Discounting Using Discount Factor Tables

Please sketch cash-flow diagrams for all these examples:

1. Find the future amount at the end of seven years of a present amount of $100 which grows at a rate of 9 percent annually.

2. Find the present value of $1,000 to be received at the end of 20 years when the discount rate is 10 percent. (Sketch a cash-flow diagram.)

EXERCISE C1 (CONTINUED)

3. You are notified that you have won the million-dollar lottery, and that you will receive the $1,000,000 in $50,000 installments paid at the end of each of the next 20 years. Assuming your personal discount rate is 10 percent, what is the present value of your prize?

4. What is the estimated present value of a $10,000 cost (in constant dollars) to be incurred five years from now, based on a 4 percent (real) discount rate?

EXERCISE C1 (CONTINUED)

5.   What is the estimated present value of a uniform annual cost of $1,000 (in constant dollars) that is expected to recur over the next 20 years, if the discount rate is 4 percent (real)?

6.   What is the present value of the energy savings from a retrofit project in Seattle that reduces annual electricity bills in a federal office building by $5,000 at today's prices, assuming that savings accrue over the next 25 years?

CALCULATING LIFE-CYCLE COSTS

MODULE D   Lecture, Discussion, Exercises

Objectives

At the conclusion of this session, you will be able to

- Summarize the federal criteria for an economic evaluation of energy-related investments

- Calculate the life-cycle costs of alternative projects

- Decide whether to accept or reject a project based on life-cycle cost calculations

Federal Criteria

Federal Criteria Summary

- DOE discount rate
- Constant dollars
- Present values
- Quantity of energy at meter
- Local energy prices
- DOE energy price escalation rates
- Maximum study period 25 years
    (+ planning/construction period)
- No evaluation required under certain conditions

NOTES:

Life-cycle Cost Calculation - Example

Heating and Cooling System

- **BASE CASE:** Baseboard Heating System with
  Window Air Conditioners

- **ALTERNATIVE:** Heat Pump

Location: Near Washington, DC

Discount Rate: Current FEMP discount rate

$ Amounts: Costs and benefits stated in base-year dollars

Energy Prices: Current, local energy prices and DOE price
escalation rates

Assumptions: Commercial electricity rates in effect
Both systems must meet performance
requirements of building

NOTES:

Project Description: An economic evaluation is needed to decide whether to choose a baseboard heating and window air conditioning system or a heat pump for a ranger's house in a national park.

Life-Cycle Cost Calculation

Base Case
Baseboard Heating System with
Window Air Conditioners

Purchase and Installation Costs:	**$1,500**
Baseboard heaters: **$ 500**	
Window air conditioners: **$1,000**	
Replacement costs	**$0**
Residual value (10% of initial cost)	**$150**
Baseboard: **$ 50**	
Window air conditioners: **$100**	
Annual electricity consumption:	**15,000 kWh**
Current price of electricity:	**$0.08 / kWh**
Annual maintenance costs:	**$50**
Air conditioner repair in year 8:	**$400**
Useful life:	**15 years**
Study period:	**15 years**

NOTES:

Life-Cycle Cost Calculation

Alternative System

Heat Pump

Purchase and Installation Costs:	$3,000
Replacement costs:	$0
Residual value (10% of initial cost)	$300
Annual electricity consumption:	10,250 kWh
Current price of electricity:	$0.08/kWh
Annual maintenance costs:	$100
Compressor repair at end of year 8:	$600
Useful life:	15 years
Study period:	15 years

NOTES:

Life-Cycle Cost Calculation

Calculate Life-Cycle Costs
for Each Alternative

LCC =   PV Initial investment Costs (I)
        + PV Replacement Costs   (Repl)
        - PV Residual Value   (Res)
        + PV Energy Costs   (E)
        + PV OM&R   (OM&R)

NOTES:

Life-Cycle Cost Calculation

<div style="border:1px solid black; padding:1em;">

LCC of Base Case

I   = \$1,500

Repl   = 0

Res   = \$150 x SPV_{15}

E   = \$1,200 x $UPV^*_{Reg3,Com,Elec,15}$

OM&R = (\$50 x UPV_{15}) + (\$400 x SPV_8)

LCC =   \$1,500
         - (\$150 x 0.547)
         + (\$1,200 x 11.33)
         + (\$50 x 11.04) + (\$400 x 0.725)

LCC = \$1500 - \$82 + \$13,596 + (\$552 + \$290)

LCC = \$15,856

</div>

NOTES:

Life-Cycle Cost Calculation

<div style="border: 1px solid black; padding: 1em;">

LCC of Alternative

I	$= \$3,000$
Repl	$= 0$
Res	$= \$300 \times SPV_{15}$
E	$= \$820 \times UPV^*_{Reg3,Com,Elec,15}$
OM&R	$= (\$100 \times UPV_{15}) + (\$600 \times SPV_8)$

$$LCC = \$3,000$$
$$- (\$300 \times 0.547)$$
$$+ (\$820 \times 11.33)$$
$$+ (100 \times 11.04) + (\$600 \times 0.725)$$
$$LCC = \$3,000 - \$164 + \$9,291 + (\$1,104 + \$435)$$

LCC = $13,666

</div>

NOTES:

Life-Cycle Cost Calculation

Calculate Net Savings
of Heat Pump from LCCs:

$$NS = LCC_{BC} - LCC_A$$

$$= \$15,856 - \$13,666$$

$$NS = \$2,190$$

NOTES:

BC = base case
A = alternative

Life-Cycle Cost Calculation

General Formula for LCC

PV of all costs, net of benefits,
over the study period:

$$LCC = \sum_{t=0}^{N} \frac{C_t}{(1 + d)^t}$$

NOTES:

$N =$ length of study period.
$C_t =$ all costs in year t.

Life-Cycle Cost Calculation

Slide D10

<div style="border:1px solid">

LCC Formula for
Building Energy Economics

LCC = I_o + Repl - Res + E + OM&R

</div>

NOTES:

All costs in present-value terms:

I_o	=	initial investment cost
Repl	=	capital replacements
Res	=	Residual value
E	=	energy costs
OM&R	=	operating, maintenance, and repair costs

SUMMARY OF FEDERAL LCC CRITERIA

Slide D1

The following criteria, consistent with the FEMP rules outlined in 10 CFR 436, specifically apply to the economic evaluation of energy and water conservation projects in federal buildings:

Discount rate

The Department of Energy determines each year the discount rate to be used in the economic analysis of energy conservation, water conservation, and renewable energy projects in federal facilities. This discount rate is based on the long-term borrowing rate of the Federal Government. It is a **real** rate, that is, **it excludes the rate of general price inflation**. The DOE discount rate and corresponding discount factors are updated annually on October 1 and published in NISTIR 85-3273, *Energy Price Indices and Discount Factors for Life-Cycle Cost Analysis*, the Annual Supplement to NBS Handbook 135 and NBS Special Publication 709.

Constant dollars

It is recommended that all future dollar amounts be estimated in **constant** dollars, with **the purchasing power of the dollar fixed** as of the base date. This convention eliminates the need for estimating the rate of general price inflation over the study period. However, the FEMP rule allows the option of estimating future dollar amounts in **current** dollars, that is, in dollars that **include the rate of general price inflation**. If future amounts are estimated in **current** dollars, a **nominal** discount rate (i.e., a rate which includes general price inflation) is needed to discount future dollar amounts to present value.

Present values

For reasons of consistency, the FEMP rule prescribes the use of present value analysis for evaluating energy- and water-related projects, i.e., all future dollar amounts should be discounted to the base date of the project. Note that "present-value" amounts are not the same as constant dollar amounts as of the base-date, since the latter do not reflect the time-value of money.

Energy prices

The FEMP LCC method uses **local energy and water prices at the building site** in calculating the **annual dollar value** of the energy or water consumed by a building or building system. Local energy and water prices should reflect the type of rate charged (residential, commercial, or industrial), differences between summer and winter rates, the impact of block rates on marginal energy and water costs, and demand charges. The analyst should not artificially adjust energy or water prices to reflect environmental externalities.

If fuel is purchased for on-site electricity generation, the costs of the fuel at the point of generation, plus the costs incurred in generating and distributing the electricity, should be used in the analysis.

Quantity of energy and water usage

Since the FEMP LCC method uses local energy and water prices at the building site, energy and water quantities should be stated **in units consistent with unit prices at the point of metering.** Equivalent quantities of energy or water at some earlier point in the supply chain (e.g., oil or coal prices before conversion to electricity) should not be used.

DOE energy price escalation rates

Energy prices are assumed to change at rates different from the rate of general price inflation. DOE projects real (differential) energy price escalation rates yearly for the next 35 years, by Census region, rate type and fuel type. These **real energy price escalation rates** and the current DOE discount rate, are used to calculate the **modified present value factors (UPV* factors)** for use in FEMP LCC analyses. The UPV* factors are updated and published annually as a set of tables in NISTIR 85-3273, the Annual Supplement to Handbook 135. At present there are no equivalent DOE projections of escalation rates for water costs.

The real price escalation rates for energy costs are incorporated into LCC evaluations in the following ways:

(1)   by multiplying the appropriate UPV* factor by the base-year annual energy cost (or savings) to calculate a present value; or

(2)   by using the most recent version of the NIST BLCC computer program, which reads the DOE-projected differential escalation rates from a file on the diskette and automatically computes the present value of energy costs

Items other than energy and water costs in FEMP studies **are generally assumed to have a zero real escalation rate** unless there is documentable evidence to the contrary. This is equivalent to saying that the prices of non-energy items are assumed to change at the same rate as general price inflation.

Study period

The maximum study period for federal energy conservation projects is 25 years from the date of occupancy of a building or the date of operation of a system. Any lead-time for planning, design, or construction may be added to the 25-year maximum study period.

The study period should be the same for all alternatives under consideration and the lesser of 25 years or the estimated use of the building or life of the system. Replacement costs and residual values, such as a salvage value, a disposal cost, or a resale value, are used to equalize the study period for the various alternatives.

For evaluating energy use and related investments in a leased federal building, the study period is the lesser of 25 years or the effective remaining term of the lease, including renewal options likely to be exercised.

No evaluation required

The FEMP rule states that:

(1)   A project is presumed **cost-effective** if it saves energy and if the costs of implementing the energy conservation measure are insignificant, and

(2)   a project is presumed **not cost-effective** if the building is
   (a)   occupied under a one-year lease without renewal option or with a renewal option that is not likely to be exercised;
   (b)   occupied under a lease that includes the cost of utilities in the rent, with no pass-through to the government of energy savings; or
   (c)   scheduled for demolition or retirement within one year.

LIFE-CYCLE COST CALCULATION

Slides D2 to D8

LCC calculation for Electric Resistance/Heat Pump example.

Formulas
Slides D9 and D10

The generic algebraic formula for calculating life-cycle costs shows that **LCC is the summation of all costs of a project, net of benefits, over the years of the study period**. Both investment-related costs and operating-related costs are included, as is spelled out in the formula for FEMP analyses.

EXERCISE D1
Calculating LCC, NS, and SIR

Use LCC, NS, and SIR to determine if adding a solar hot water system to a military launderette, currently using electric resistance energy for water heating, is a cost-effective project. The two alternatives are to

(1) Base case: continue using the existing hot water system as is, or

(2) Alternative: add a solar hot water system and use the existing system for auxiliary heating.

Data and Assumptions:

Location:	Arizona
Annual Hot Water Usage:	1,750 million Btu/year
Today's Price of Electricity:	Industrial rate: $0.08/kWh
Annual Quantity of Electricity:	513,000 kWh ($\approx$1,750 10^6 Btu @ 3,412 Btu/kWh)
	(1 kWh = 3,412 Btu)

Base Case:

Electric Resistance (ER) Hot Water Heater

Annual electricity usage:	513,000 kWh
System Life:	15 years
Residual Value:	0

Alternative: Solar Hot Water System with existing system for auxiliary heating:

60% of hot water load supplied by solar
40% of hot water load supplied by existing system

Cost of purchasing and installing solar system:	$140,000
Annual electricity to operate solar system:	6,160 kWh
Annual electricity for auxiliary:	205,200 kWh (= 0.40 x 513,000)
Annual OM&R for solar system:	3% of purchase and installation cost
System life:	15 years
Residual value:	0

Note: OM&R for the existing system is the same for both the base case and the alternative. Only the additional OM&R for the solar system needs to be included in the analysis.

BLCC COMPUTER PROGRAM

MODULE E   Lecture, Discussion, Exercises

Objectives

At the conclusion of this session, you will be able to

- Run the BLCC computer program

- Set up and solve a lowest-LCC problem using BLCC

- Compute measures of economic performance for a project alternative

INTRODUCTION TO
THE NIST BLCC PROGRAM
Version 4.3-96

NOTES:

The User's Guide for the BLCC program (version 4.3) is published by NIST as NISTIR 5185-3.

BLCC is updated each year on October 1 to include the current DOE discount rate and the DOE energy price escalation rates.

Overview - BLCC Version 4.3

■ **Economic analysis of capital investments that reduce future costs**

■ **Focus on energy and water conservation in buildings**

■ **Federal, DoD, state, local government, and private sector applications**

■ **Runs on IBM-PC and compatibles**

■ **Supporting programs: Quick Input, ERATES, EMISS**

NOTES:

BLCC Reports

■ For individual project alternatives
  – Input data listing
  – Life-cycle cost analysis (detailed and summary)
  – Yearly cash flow analysis

■ Comparative analyses:
  – Listing of LCCs for all project alternatives,
    with lowest LCC flagged
  – Comparative economic measures (alternative
    versus base case)
    • Side-by-side comparison of present values
    • Net Savings
    • Savings-to-Investment Ratio
    • Adjusted Internal Rate of Return
    • Payback
    • Energy Savings
    • Emission Reductions

NOTES:

BLCC for Federal Buildings

- FEMP guidelines for energy- and water-related investments

- OMB A-94 guidelines for non-energy investments

- DoD guidelines for military construction

- Current DOE and OMB discount rates

- Current DOE projections of energy price escalation rates

- Constant-dollar analysis only

NOTES:

Typical BLCC Data Requirements for Federal Analysis

■ **General Assumptions:**
- – Analysis type
- – Base date
- – Service date
- – Study period
- – Discount rate
- – Discounting convention

■ **Capital Investment Data:**
- – Initial cost
- – Cost Phasing
- – Capital replacements
- – Residual values

■ **Operation-related Data:**
- – Annual recurring OM&R cost
- – Non-annual recurring OM&R cost
- – Energy consumption and cost data
- – Water consumption and cost data

NOTES:

MAIN BLCC MENU

Enter/Edit/Print Input Data
Individual Project Alternative Reports
Comparative Analysis Reports
Quick Input Program
Set Up
General Information
EXit

Create New Input File
Edit Existing Input File
Print Input Data Report
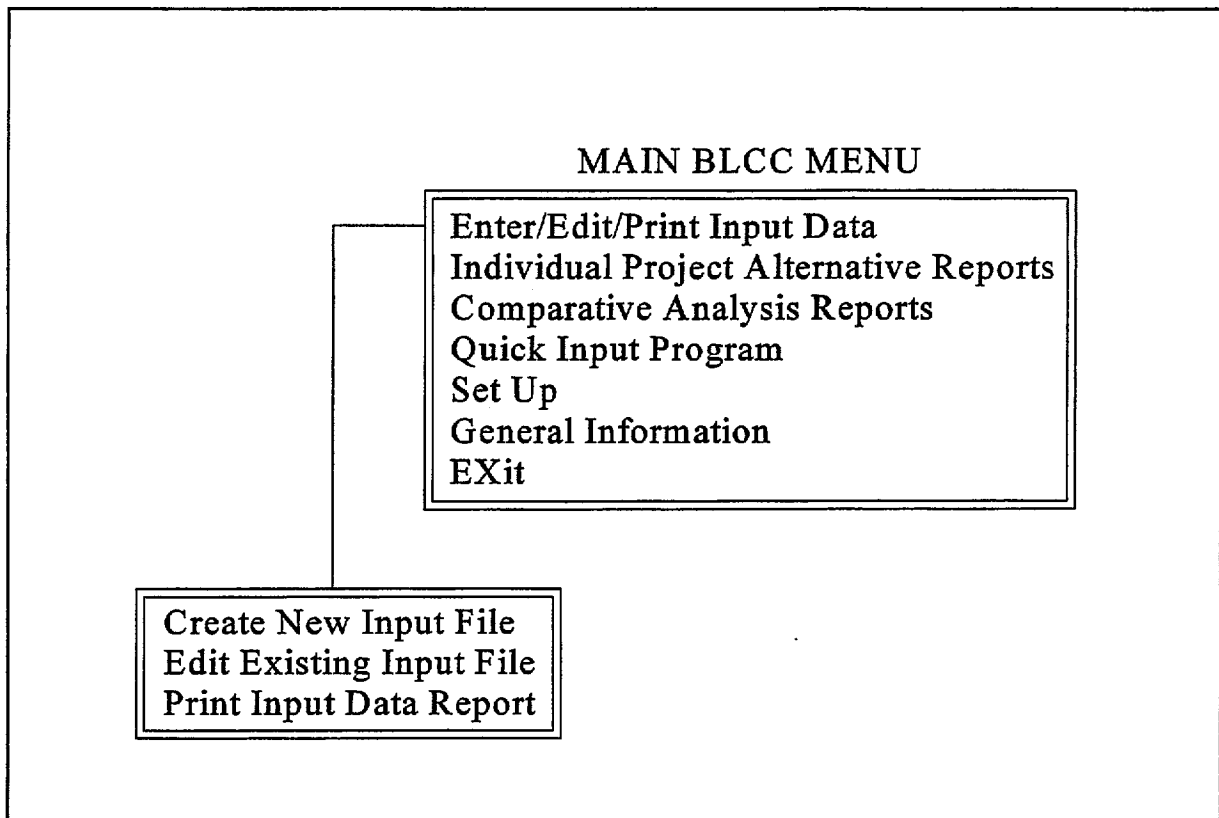
NOTES:

Creating a BLCC Input File

■ Create separate input file for each project alternative

■ Declare LCC analysis type (federal, DoD, general, etc.) up front

■ Highlight menu choices and press Enter; Escape to move back

■ Complete data entry forms on screen

■ Definitions of all input variables in User's Guide

■ Use PgDn to move to next form; PgUp (or Escape) to move back

■ Input file saved using user-supplied filename (extension = DAT)

■ LCC computations are made each time input file is saved

■ LCC computations saved using user-supplied filename (extension = LCC)

NOTES:

Types of LCC analyses that can be performed by BLCC

(1) Federal Analysis - - Energy Conservation Projects
(2) Federal Analysis - - Projects Subject to OMB A-94
(3) Private Sector - - Buildings with Tax Analysis
(4) Private Sector - - Owner - Occupied Houses
(5) General LCC Analysis - - Non-Federal, No Taxes
(6) MILCON Design - - Energy Conservation Projects
(7) MILCON Design - - Projects Subject to OMB A-94

NOTES:

Project data entry screen

Project Name: Heating System
Project Alternative: Heat Pump #1
Base Date of Study (Month/Year): 1/1993   (e.g., 3/1994)
Service Date   (Month/Year): 1/1993   (e.g., 3/1995)
Study Period Length (Years/Months from Base Date): 30/0 (e.g., 20/0)
Discount rate: 4.00%
End-of-year or Mid-year discounting (E/M): _____
Comment:_____

NOTES:

Slide E10

Declaration of capital components

Do you wish to break down capital costs by component in this file,
(e.g., envelope, windows, insulation, HVAC, . . . Y/N)? Y

How many components in this project (1-6)? 3

NOTES:

This option is generally used with LCC analyses for whole buildings. Do not use this option to
evaluate multiple alternatives.

CAPITAL INVESTMENT DATA

Initial Cost (Base Year Dollars): $10000
Expected Life (from Occupancy, Years/Months): 20/0
Resale Value Factor (% of Initial Cost): 10.0 %
Price Escalation Rate before Service Date: 0.0 % / year
Price Escalation Rate after Service Date: 0.0 % / year

NOTES:

Slide E12

Annually-Recurring Operating/Maintenance/Repair Costs

Amount (base Year Dollars): $1000
Annual rate of increase: 0.00%

NOTES:

Non-Annually-Recurring Operating/Maintenance/Repair Costs

Ys/Ms	Cost	Ys/Ms	Cost	Ys/Ms	Cost	Ys/Ms	Cost
10/0	1000						
20/0	1000						
___	___						

NOTES:

Include *non-capital* replacement costs here (i.e., replacements that are not considered to be capital investments).

Capital Replacement Cost Schedule

Capital Replacement:	#1	#2	#3	#4
Years/Months (from Service Date):	10/0	___	___	___
Initial Cost (base yr $) :	$5000	$ ___	$ ___	$ ___
Expected Life (years / months) :	10/0	___	___	___
Resale Value Factor:	0.0%	___ %	___ %	___ %

NOTES:

Only include *capital* replacements here (i.e., replacements that are considered to be capital investments). Only four capital replacements are permitted for each project component.

Slide E15

Main Energy Screen

	A	B	C	D
Energy Type Code (1-9)*:	1	2	4	–
Units Code (1-12)**:	1	2	3	–
Base Annual Consumption (units/yr):	10000	2000	3000	
Price/unit (base year dollars):	$0.100	$1.000	$1.000	$
Annual Demand-related Charge:	$500	$0	$0	$
Escalation Type Code (1-3)***:	2	2	2	–

NOTES:

*Energy Type Codes

1 = Electricity	5 = Liquified Petroleum Gas
2 = Distillate Fuel Oil (#1, #2)	6 = Coal
3 = Residual Fuel Oil (#4, #5, #6)	7 = Central Steam
4 = Natural Gas	8 = Chilled Water
	9 = Other

**Unit Codes

1 = kWh	5 = Pound	9 = kg (kilograms)
2 = Gallon	6 = MJ (megajoules)	10 = ft^3
3 = Therm	7 = GJ (gigajoules)	11 = m^3
4 = MBtu (million Btu)	8 = l (liter)	12 = MWh

***Escalation Type Codes

1 = User's own escalation rates
2 = DOE escalation rates from disk
3 = User modifies DOE escalation rates

Slide E16

Data required for DOE energy price escalation rates

Rate Schedule Type*   (1-3): <u>1</u>
State Abbreviation (2-char): <u>DC</u>

NOTES:

*Rate Schedule Type--the type of utility rate schedule used for the project. Choose one:

1 = residential
2 = commercial
3 = industrial

Data entry is now complete

Save Input Data & Compute LCC
Review Input Data File
Exit without Saving

Use cursor to make selection, then press <Enter>.
(or press highlighted letter)

NOTES:

Data entry fields for filenames

Enter filename for saving Input Data File: ▓▓▓▓▓ .DAT
Default file name = DEMO1

Enter filename for saving LCC Output File: ▓▓▓▓▓ .LCC
Default file name = DEMO1

NOTES:

Do **NOT** include drive/directory or extension in filename.

Slide E19

Summary LCC Report for file DEMO1.DAT

	PRESENT VALUE	ANNUAL VALUE
INITIAL COST (AT OCCUPANCY)	$9,527	$724
ANNUALLY RECURRING OM&R COSTS	$11,304	$859
NON-AN. RECURRING OM&R COSTS	$899	$68
ENERGY COSTS	$89,097	$6,769
REPLACEMENT COSTS	$2,784	$212
LESS: REMAINING VALUE	($342)	($26)
TOTAL LCC	$113,269	$8,605

NOTES:

Slide E20

```
MAIN BLCC MENU

Enter/Edit/Print Input Data
Individual Project Alternative Reports
Comparative Analysis Reports
Quick Input Program
Set Up
General Information
EXit


Print Summary LCC Report
Print Detailed LCC Report
Print Annual Cash Flow Report
```

NOTES:

Slide E21

MAIN BLCC MENU

Enter/Edit/Print Input Data
Individual Project Alternative Reports
Comparative Analysis Reports
Quick Input Program
Set Up
General Information
EXit

Find Lowest LCC (up to 99 Alternatives)
Comparative Measures (Alternative vs Base Case)

NOTES:

Slide E22

Lowest LCC Report

COMPARATIVE PRESENT-VALUE COSTS OF ALTERNATIVE PROJECTS
(Shown in ascending order of initial cost, * = lowest LCC)

PROJECT NAME	LCC FILENAME	INITIAL COST (PV)	LIFE CYCLE COST (PV)
demo one	DEMO1	$9,527	$113,269
demo two	DEMO2	$10,479	$105,007
demo three	DEMO3	$11,432	$100,896*
demo four	DEMO4	$14,290	$100,936

NOTES:

Note that initial cost may not be the same as investment cost, which includes capital replacements and residual (resale) value.

Only alternatives that have the same underlying economic assumptions (study period, discount rate, base date, etc.) can be compared.

EXERCISE E1
COMPUTER LAB #1
Selecting a Residential Heating and Cooling System

Using BLCC, compute and compare the LCCs of a baseboard electric system/window air conditioner and heat pump for installation in a new Park Service house in Washington D.C. Compute the NS and SIR for the heat pump relative to the baseboard/window AC system.

Common Assumptions:

Study period = 15 years
Discount rate = current DOE discount rate
Planning/construction period = 0
Current price of electricity = $0.08/kWh
Use DOE escalation rates for energy prices
Rate type = commercial
State = DC

Cost data:

Baseboard electric heater with window air conditioners (base case):

Initial cost (installed):		
Baseboard heaters	=	$500
Window AC	=	$1,000
Expected lives (both)	=	15 years
Resale value at end of study period:		
Baseboard heaters	=	10% of initial cost
Window AC	=	10% of initial cost
Annually recurring OM&R costs:		
Baseboard heaters	=	0
Window AC	=	$50
Non-annually recurring OM&R costs:		
Baseboard heaters	=	0
Window AC	=	$400 in year 8
No capital replacements		(life = study period)
Annual energy consumption	=	15,000 kWh (constant)

Heat Pump (alternative case):

Initial cost (installed)	=	$3,000
Expected life	=	15 years
Resale value at end of study period	=	10% of initial cost
Annually recurring OM&R costs	=	$100
Non-annually recurring OM&R costs	=	$600 in year 8
No capital replacements		(life = study period)
Annual Energy Consumption	=	10,250 kWh (constant)

Suggested Approach to Exercise E1

Warning!

Do not start in file edit mode with the demo files from the disk.
Do not attempt to include both alternatives in the same input file.
Read these recommended procedures first.

Recommended procedures:

From the main BLCC menu, select the "Enter/Edit/Print Input Data" option, then "Create New Input File" option. Enter data for the baseboard system with window AC. You can break down capital costs by component (i.e., enter data separately for the baseboard heater and the window air conditioner) or combine them as a single component. There are no capital replacement costs in this problem. Use the DOE escalation rates for energy prices (rather than your own rates) and select constant annual energy consumption. When data entry is complete, save the data file and display the summary LCC report that is generated when the LCC is computed as the file is saved. Display the summary report to the screen for now and check with the instructor to verify that you have the correct result.

Then create a second input data file for the heat pump. Rather than creating this second file from scratch, edit the first file, changing only those variables that are different. (If you broke down the input data file for the baseboard/AC system into components, you will have to rename the first component and delete the second component.) Save this input file under a different filename than the baseboard/AC system so that you do not erase the first file.

From the main menu, choose the option "Comparative Analysis Reports" and then choose the option "Find Lowest LCC". Tag the names of the two LCC data files by pressing the space bar when their names are highlighted. Press <Enter> when the file names are tagged. Display the report to the screen. Check with the instructor to see that you have the correct results.

Finally, choose the option "Comparative Analysis Reports" and then choose the option "Comparative Measures". Tag the names of the two LCC data files by pressing the space bar when their names are highlighted. Press <Enter> when the file names are tagged. Display the report to the screen.

Calculating Supplementary Economic Measures

MODULE F   Lecture, Discussion

Objectives

At the conclusion of this session, you will understand

- How the supplementary economic measures

  Net Savings,
  Savings-to-Investment Ratio,
  Adjusted Internal Rate of Return, and
  Discounted Payback Period

- are related to the LCC measure

- are calculated

- are applied to economic evaluation problems

Net Savings

Net Savings (NS)

$$NS_{A:BC} = \sum_{t=0}^{N} \frac{S_t}{(1 + d)^t} - \sum_{t=0}^{N} \frac{\Delta I_t}{(1 + d)^t}$$

where $NS_{A:BC}$ = Present value of Net Savings of the alternative relative to the base case

S_t = Savings in year t in operating-related costs attributable to the alternative

ΔI_t = Additional investment-related costs attributable to the alternative

NOTES:

Net Savings

Net Savings

$$NS = \text{PV of operating-related savings}$$
$$\text{minus PV of additional investment}$$

$$= [\Delta E + \Delta OM\&R] - [\Delta I_o + \Delta Repl - \Delta Res]$$

where $\Delta E \quad = (E_{BC} - E_A)$

$\Delta OM\&R = (OM\&R_{BC} - OM\&R_A)$

$\Delta I \quad = (I_A - I_{BC})$

$\Delta Repl = (Repl_A - Repl_{BC})$

$\Delta Res = (Res_A - Res_{BC})$

all in present values

NOTES:

Net Savings

Savings from Heat Pump

**Base Case (BC):Baseboard Heater and Window Air Conditioners
Alternative (A):Heat Pump**

	BC = BB/AC	A = HP	Operating-related savings
Annual energy costs	$1,200	$820	$380
Annual maintenance costs	$50	$100	-$50
Repair costs	$400	$600	-$200
			Additional investment costs
Initial investment	$1,500	$3,000	$1,500
Replacement costs	0	0	0
-Residual value	($150)	($300)	-$150

NOTES:

Data from example in Section D.

Net Savings

Net Savings for Heat Pump

PV Operating-related savings (BC-A):

ΔPV Energy:	$380 x 11.33 =	$4,305
ΔPV Annual O&M:	-$50 x 11.04 =	-$552
ΔPV Repair:	-$200 x 0.725 =	-$145

Total   **$3,608**

PV Additional investment costs (A-BC):

ΔPV Initial investment:		$1,500
ΔPV Replacement:		0
ΔPV Residual value:	-$150 x 0.547 =	-$82

Total   **$1,418**

$$NS_{HP} = \$3{,}608 - \$1{,}418 = \$2{,}190$$

NOTES:

Net Savings

Uses of Net Savings Method

Type of Decision	NS	Criterion
Accept / Reject	yes	>0 / <0
Level of Efficiency	yes	maximize
System Selection	yes	maximize
Interdependent Systems	yes	maximize
Project Priority	no	---

NOTES:

Savings-to-Investment Ratio

Savings-to-Investment Ratio (SIR)

$$SIR_{A:BC} = \frac{\sum_{t=0}^{N} S_t / (1 + d)^t}{\sum_{t=0}^{N} \Delta I_t / (1 + d)^t}$$

$SIR_{A:BC}$ = The ratio of PV savings to additional PV investment costs of the alternative relative to the base case

S_t = Savings in year t in operating-related costs attributable to the alternative, i.e., $\Delta(OMR_t + E_t)$

ΔI_t = Additional investment-related costs attributable to the alternative

NOTES:

Savings-to-Investment Ratio

Savings-to-Investment Ratio for Heat Pump Example

$$SIR_{HP} = \frac{[\Delta E + \Delta OM\&R]}{[\Delta I_o + \Delta Repl - \Delta Res]}$$

PV of operating-related savings of heat pump: = $3,608

PV of additional investment costs: = $1,418

$$SIR = \frac{\$3,608}{\$1,418}$$

SIR = 2.54

NOTES:

Savings-to-Investment Ratio   Slide F8

Uses of Savings-to-Investment Ratio

Type of Decision	SIR	Criterion
Accept / Reject	yes	>1.0 / <1.0
Level of Efficiency	no	---
System Selection	no	---
Interdependent Systems	no	---
Project Priority	yes	descending order of SIR

NOTES:

Adjusted Internal Rate of Return

Adjusted Internal Rate of Return

Measures the performance of an investment as a percentage yield, assuming reinvestment of cash flows at a given rate (r).

$$AIRR = (1 + r) \, SIR^{1/N} - 1$$

NOTES:

Adjusted Internal Rate of Return

<div style="border:1px solid black">

Adjusted Internal Rate of Return
for Heat Pump Example

$$\text{AIRR} = (1 + r)\ \text{SIR}^{1/N} - 1$$

$$\text{AIRR}_{HP} = (1 + 0.041)\ 2.54^{1/15} - 1 = 0.1077$$

$\text{AIRR}_{HP} = 10.8\%$

</div>

NOTES:

*

Adjusted Internal Rate of Return

Uses of Adjusted Internal Rate of Return

Type of Decision	AIRR	Criterion
Accept / Reject	yes	>MARR / <MARR
Level of Efficiency	no	---
System Selection	no	---
Interdependent Systems	no	---
Project Priority	yes	descending order of AIRR

NOTES:

Discounted Payback

Discounted Payback (DPB)

Find the minimum value of N, years, for which

$$\sum_{t=1}^{N} \frac{(S_t - \Delta I_t)}{(1 + d)^t} \geq \Delta I_o$$

where

$S_t =$ **Savings in year t in operating-related costs for the alternative**

$\Delta I_t =$ **Additional investment-related costs in year t, other than initial investment**

ΔI_o **Additional initial investment for the alternative**

NOTES:

Discounted Payback

Discounted Payback for Heat Pump

Annual Energy Savings = $380
Additional OM&R Costs = $50 annually + $200 in year 8
Additional Investment = $1,500

Year	Cumulative PV Savings	Initial Cost	Cumulative Net Savings
1	$317	$1,500	-$1,183
2	622	1,500	-872
3	915	1,500	-585
4	1,199	1,500	-301
5	1,472	1,500	-$28
6	1,737	1,500	+237*
7	1,995	1,500	+495
8	2,097	1,500	+597

Discounted Payback occurs early in year 6

NOTES:

Discounted Payback   Slide F14

<table>
<tr><td colspan="3" align="center">**Uses of Discounted Payback Period**</td></tr>
<tr><td>**Type of Decision**</td><td>**DPB**</td><td>**Criterion**</td></tr>
<tr><td>Accept / Reject</td><td>yes</td><td>≤project life*/ >project life</td></tr>
<tr><td>Level of Efficiency</td><td>no</td><td>---</td></tr>
<tr><td>System Selection</td><td>no</td><td>---</td></tr>
<tr><td>Interdependent Systems</td><td>no</td><td>---</td></tr>
<tr><td>Project Priority</td><td>no</td><td>---</td></tr>
</table>

NOTES:

*DPB is consistent with LCC only if
(1) cumulative net savings do not turn negative after payback is reached, and
(2) residual values, if any, are included if payback ≥ to study period.

SUPPLEMENTARY ECONOMIC MEASURES

The FEMP rule prescribes the LCC method for evaluating energy conservation projects in federal buildings. The LCC method is the most complete indicator of the estimated cost of obtaining, utilizing, and disposing of a building or building system. It permits careful consideration of the use, cost, and conservation of energy, an advantage particularly important for federal buildings, for which energy conservation is a statutory requirement.

To supplement LCC analysis, there are additional measures of economic effectiveness, such as Net Savings (NS), Savings-to-Investment Ratio (SIR), Adjusted Internal Rate of Return (AIRR), and Discounted Payback (DPB) period. Since all of these measures are based on life-cycle costs, they are consistent with the LCC method, if applied correctly.

Particular care must be given to the use of the DPB as a criterion for accepting or rejecting projects. It is only consistent with the LCC method when nothing more is required than that payback occur before the end of the study period and if cumulative net savings after payback is achieved are positive. DPB is not consistent with the LCC method when an arbitrary payback period is specified as a cut-off point for project acceptance.

Net Savings (NS)   Slides F1 to F5

NS is a measure of long-run profitability of an alternative relative to a base case. The NS method is a variation of the Net Benefits (NB) method and is used when benefits occur primarily in the form of cost reductions. The NS gives the amount, in today's dollars, that the alternative will save over the study period, over and above the dollars that would have been earned at the Minimum Acceptable Rate of Return (MARR). The MARR is equal to the discount rate.

The NS can be calculated as an extension of the LCC method to show the **difference between the total LCC of a base case and the total LCC of an alternative.** It can also be calculated **directly** from differences in the individual cash flows between a base case and an alternative.

The NS method can be used to:

(1)   *Determine a project's cost effectiveness:* **A project is considered cost effective if its NS is positive.** For example, an NS value of $50,000 for an alternative building system means that the system is estimated to save over the study period an amount equivalent to a lump-sum amount today of $50,000, over and above the savings that would be earned at the MARR.

(2)   *Compare designs or levels of efficiency of buildings and building systems:* The NS method can be used to choose the most cost-effective design or level of efficiency among buildings or building systems (e.g., alternative configurations of a building or designs of a heating system; alternative thicknesses of insulation). The alternative with the highest NS compared to the base case is the most cost-effective choice. **Choosing a project with the highest NS is equivalent to choosing a project with the lowest life-cycle cost.**

(3)   *Find the optimal combination of interdependent building systems.* Determining the optimal design or level of efficiency of interdependent systems requires that the interaction between systems be taken into account. The combination with the greatest **overall** NS is the economically optimal combination.

Savings-to-Investment Ratio (SIR)   Slides F6 to F8

The SIR is a method of evaluation that expresses the ratio of savings to costs. It is a variation of the Benefit-to-Cost Ratio (BCR) and is used instead of the BCR method when benefits occur primarily as cost reductions.

The numerator of the ratio contains the operating-related savings (e.g., reductions in energy costs and differences in OM&R costs); the denominator contains the increase in investment-related costs (e.g., increases in initial investment costs, and differences in replacement costs and residual values).

The SIR can be used to:

(1)   *Determine a project's cost effectiveness:* **An SIR greater than one generally means that a project is cost effective.** The higher the ratio, the greater the dollar savings per dollar spent. For example, an SIR of 4.0, computed for an alternative system relative to the base case, means that the alternative system is estimated to save $4.00 on the average for every $1.00 invested, over and above the amount that can be earned at the MARR.

(2)   *Rank independent projects to determine their relative priorities:* **The SIR is recommended for setting priority among projects** when the budget is insufficient to fund all cost-effective projects. The projects are ranked in descending order of their SIRs. This ranking will provide a reliable guide to choosing the group of independent projects that maximizes overall net savings for the budget, provided that the budget can be used up exactly.

If project costs are "lumpy," so that the budget cannot be used up exactly, it may be necessary to depart from the SIR ranking of individual projects in order to maximize the overall NS from the total budget. In this case, overall NS can be computed for trial combinations to find the set of projects that maximizes overall NS and stays within the confines of the budget.

Note that the SIR method is not reliable for selecting the optimal energy efficiency level or the optimal system or design unless the analysis is based on incremental SIRs.

Adjusted Internal Rate of Return (AIRR)   Slides F9 to F11

The internal rate of return measures the economic performance of an investment as a percentage yield. The yield is compared against an investor's MARR. For an investment to be attractive, the IRR has to be higher than the MARR.

The Adjusted Internal Rate of Return (AIRR) replaces the traditionally used Internal Rate of Return (IRR). The IRR has various shortcomings which limit its usefulness. For example, it is possible to get multiple solutions for the IRR if there are cash flows that switch from positive to negative during the study period. A more serious shortcoming is that the IRR may over- or understate a project's profitability because it assumes implicitly that amortized cash flows are reinvested at the calculated IRR.

The **AIRR is a more accurate return measure** because it **adjusts the cash flows correctly by using an explicit reinvestment rate**, different from the calculated IRR. Typically it is the discount rate that is used as the reinvestment rate since it is the investment rate for the next best investment opportunity.

If a rate-of-return measure is used for allocating federal budgets for energy conservation, it is the AIRR that must be used rather than the IRR, because the AIRR is consistent with the LCC and NS methods, which also use the discount rate in their computations.

An added advantage of the AIRR is that it can be computed algebraically whereas the IRR has to be found by iteration. If the SIR of an alternative is already known, there is an especially simple way to calculate the AIRR by using a formula that combines the SIR with the reinvestment rate.

The AIRR and the IRR are the same (1) if the investment yields a single, lump-sum benefit at the end of the study period, or (2) if the investment rate is the same as the calculated IRR.

The AIRR can be used to:

(1)   *Determine a project's cost effectiveness:* An AIRR measure greater than the MARR generally means that a project is cost effective. The AIRR is used as an option in the FEMP program for analysts who prefer to express the economic worth of a project as a percentage rate of return.

(2)   *Rank independent projects to determine their relative priorities:* The AIRR is a substitute for the SIR for ranking. Projects are ranked in descending order of their AIRRs. When used for ranking, the AIRR is subject to the same limitations as the SIR. When the budget cannot be exhausted by taking projects in descending order of their AIRRs because project costs are lumpy, it may be necessary to depart from the AIRR ranking in order to maximize the overall NS from the total budget.

     Like the SIR, the AIRR is not reliable for design and efficiency decisions unless the analysis is based on incremental AIRRs.

Discounted Payback (DPB)   Slides F12 to F14

The DPB measures how long it takes to recover initial investment costs. The measure is calculated as the number of years elapsed between the initial investment and the time at which cumulative savings, net of accrued costs, are just sufficient to offset investment costs.

The DPB takes the time value of money into account by using discounted cash flows. If the time value of money is ignored, that is, if the discount rate is assumed to be zero, the method is called Simple Payback (SPB), a measure of evaluation less accurate than the DPB.

Both the DPB and the SPB have serious shortcomings in that they ignore all costs and savings that occur after payback has been reached. For that reason, it is possible that a project design or level of efficiency with a shorter payback period is a poorer investment than one with a longer payback period when looked at over the entire study period.

The DPB should be used as a supplementary measure only, to

(1)   serve as a rough screening measure for accept/reject decisions;

(2)   assess the minimum required project life to protect initial investment funds in the face of uncertainty;

(3)   determine cost-effectiveness when potential returns beyond a certain time are irrelevant.

EVALUATING EFFICIENCY LEVELS
AND DESIGN ALTERNATIVES

MODULE G   Lecture, Discussion, Exercises

Objectives

At the conclusion of this session, you will be able to

- Determine the lowest-LCC efficiency level of
  a building system

- Determine the lowest-LCC system or design

- Evaluate interdependent systems

Optimization of INDEPENDENT Systems   Slide G1

General Optimization Rule for
Mutually Exclusive Systems:

Find the alternative with the lowest life-cycle cost.

NOTES:

Optimization of INDEPENDENT Systems   Slide G2

Determining Lowest - LCC
Energy Efficiency Level

Example:
Attic insulation in a single-family house (1200 sq. ft.)

Alternative resistance values	Installed cost
R-11	$300
R-19	$450
R-30	$650
R-38	$800
R-49	$1,000

Electric heat pump: Seasonal COP - 1.8 heating, 3.0 cooling
Price of electricity: $0.08 / kWh (residential rate)
Study period: 30 years
Discount rate: 4%
UPV* for electricity: 18.07

NOTES:

Optimization of INDEPENDENT Systems

Determining Lowest - LCC
Energy Efficiency Level

Example: Attic insulation

R Values	Annual Heating Requirements (MBtu)	Annual Cooling Requirements (MBtu)	Annual Usage (kWh)
R- 0	50.0	15.0	9,602
R- 11	38.0	13.0	7,455
R- 19	35.9	12.4	7,055
R- 30	34.6	12.0	6,804
R- 38	34.1	11.8	6,703
R- 49	33.7	11.7	6,628

NOTES:

Optimization of INDEPENDENT Systems

Determining Lowest - LCC
Energy Efficiency Level

Example: Attic insulation

Present Value Costs

R Values	I	+	E	=	LCC	SIR
R- 0	$ 0		$13,881		$13,881	---
R- 11	300		10,777		11,077	10.3
R- 19	450		10,199		10,649	8.2
R- 30	650		9,836		10,486*	6.2
R- 38	800		9,690		10,490	5.2
R- 49	1000		9,581		10,581	4.3

NOTES:

*Lowest LCC.

Optimization of INDEPENDENT Systems

Incremental Solution to
Selection of Attic Insulation

R-Values	I	Total Savings	SIR	ΔI	ΔS	Δ SIR
R- 0	$ 0	---	---	---	---	---
R- 11	300	$3,104	10.3	$300	$3,104	10.3
R- 19	450	3,682	8.2	150	578	3.9
R- 30	650	4,045	6.2	200	363	1.8
R- 38	800	4,191	5.2	150	146	0.97
R- 49	1,000	4,300	4.3	200	109	0.55

NOTES:

All costs in present values.

Optimization of INDEPENDENT Systems

Determining Lowest - LCC
System Design

Example: Residential Heating / Cooling Systems

Options Considered:	Eff (SCOP) Htg /Clg	Installed Cost	Annual Cost
Electric BB / Window AC	1.00 / 3.0	$2,000	$ 75
Heat Pump (Central)	2.00 / 3.0	4,000	200
Oil Furnace / Central AC	0.82 / 3.0	4,500	125
LPG Furnace / Central AC	0.85 / 3.0	4,500	100

Duct losses for central systems = 10%

NOTES:

Optimization of INDEPENDENT Systems

Example: Residential Heating / Cooling Systems (cont.)

Study Period: 15 years
Discount Rate (real): 4%
UPV: 11.12
Annual space heating requirements: 50 MBtu
Annual space cooling requirements: 20 MBtu

Current Energy Prices (DOE Region 2)		UPV*
Oil:	$ 8.00 / MBtu	13.17
LPG:	$11.00 / MBtu	12.90
Elec:	$22.00 / MBtu	11.24

NOTES:

Optimization of INDEPENDENT Systems

Example: Residential Heating / Cooling Systems (cont.)

System	Present Values				SIR	NS
	I	OM&R	E	LCC		
Electric BB / Window AC	$2,000	$ 834	$14,013	$16,847	---	---
Heat Pump (Central)	4,000	2,224	8,701	14,925	1.96	1922
Oil Furnace / Central AC	4,500	1,390	8,970	14,860	1.79	1987
LPG Furnace / Central AC	4,500	1,112	11,106	16,718	1.05	128

NOTES:

*Lowest LCC.

Simultaneous Optimization of INTERDEPENDENT Systems

Simultaneous Optimization of Interdependent System Alternatives

Example: Selection of envelope modifications and HVAC system

■ **As envelope becomes more thermally efficient, savings from HVAC improvements diminish**

■ **As HVAC efficiency is increased, savings from envelope improvements diminish**

■ **Lowest-LCC alternatives may change when other interdependent systems are modified**

NOTES:

Simultaneous Optimization of INTERDEPENDENT Systems

General Rule for
Simultaneous Optimization:

Find the combination of system alternatives with
the lowest overall life-cycle cost

$$LCC_i \;=\; \sum_{s=1}^{N} (I_{sj} + Repl_{sj} - Res_{sj} + OM\&R_{sj}) + E_i$$

where i = system combination
s = building system (s = 1,2, . . . , N)
j = alternative for system s (j = 1,2, . . . , n_s)

Possible combinations: $n_1 \times n_2 \times n_3 \times , . . ., \times n_N$

NOTES:

Simultaneous Optimization of INTERDEPENDENT Systems

Slide G11

Simultaneous Optimization Strategies

- Find lowest - LCC alternative for each system, using best guess for specification of other systems

- Investigate sensitivity of the lowest -LCC alternative to energy prices

- Investigate sensitivity of savings from alternatives to other system specifications:
  - Envelope systems tend to be weakly linked
  - Envelope/Lighting/HVAC interaction is stronger

- Consider only practical and balanced combinations of alternatives

NOTES:

Simultaneous Optimization of INTERDEPENDENT Systems

Slide G12

Simultaneous Optimization of Interdependent Systems Using LCC

Window Glazing

	1	2	3	
R- 0	7067	6483	6267	
R- 11	6033	5717	5633	Furnace
R- 19	5867	5603	5547	Efficiency
R- 30	5803	5580	5537*	= 75%
R- 38	5805	5595	5565	
R- 0	6882	6456	6318	
R- 11	6006	5815	5794	Furnace
R- 19	5871	5726	5729	Efficiency
R- 30	5828	5719*	5734	= 85%
R- 38	5840	5743	5770	

NOTES:

OPTIMIZATION OF INDEPENDENT SYSTEMS

Lowest-LCC energy efficiency level
and system selection   Slide G1

Optimization of a building system from an economic standpoint means finding the design alternative and performance level with the lowest life-cycle cost. In this workshop we are mostly concerned with **efficiency levels and system selections related to energy consumption.** Whether you are evaluating a single system **independently** of other systems, or several **interdependent** systems simultaneously, the economic criterion is the same: **minimize LCC.**

Supplementary economic measures, such as the SIR, AIRR, and PB, are not generally useful for identifying the energy efficiency level or the optimal system or design alternative with the lowest LCC. Sometimes these supplementary measures can be applied **incrementally** to find the optimal efficiency level or design, but they must be used with care when doing so, requiring more analysis than using the LCC rule alone.

Optimal energy efficiency level for a building system
Lowest-LCC   Slides G2 to G4

Attic insulation provides a good example for determining the optimal efficiency level for a building system. In this example five different resistance levels of attic insulation are examined to determine which has the lowest LCC. The calculations are based on space heating and cooling with an electric heat pump in a house in Ohio, DOE region 2, with electricity at \$0.08 per kWh. Note that the higher the cost of electricity, the less efficient the heating and cooling equipment, and the more severe the climate, the greater will be the savings from the insulation at each R-value, pushing the optimal level higher.

Slides G2 and G3 provide the data necessary for the economic calculations. Slide G4 shows the LCC computed for each R-value. The R-value with the lowest LCC in this example is R-30. Note that the SIR for the investment at each level decreases as more insulation is added; but in all cases the SIR is greater than 1.0. This demonstrates that the SIR computed for the **total** savings and **total** cost is not useful for identifying the R-value with the lowest LCC, since all SIRs here are greater than one.

Incremental SIR   Slide G5

Slide G5 presents additional analysis for this insulation example. The **change** in investment (ΔI) and savings (ΔS), and the resulting **change** in SIR (ΔSIR) for each additional **increment** of insulation are computed and displayed. As long as ΔSIR for each additional increment of insulation is greater than 1.0, that additional increment of insulation is cost effective and increases the total SIR. When the SIR falls below 1.0, that increment is not cost effective and no more insulation is added. This incremental analysis gives more insight into the optimization exercise, but it is only useful if the SIR decreases steadily in the relevant range of the analysis.

Optimal system selection or design alternative   Slides G6 to G8

For many building systems, the efficiency of the system is only one of the decision criteria that must be considered in the design process. The systems may be different in other respects, and these differences may also be important from an overall building performance standpoint. For example, an exterior wall may be solid masonry, wood frame with siding, or some combination of the two. Each of these designs may have different costs associated with improved energy performance, in addition to different maintenance costs. The lowest-LCC design will vary with climate, energy costs, and maintenance costs.

In the example shown in slides G6 through G8, different heating/cooling systems are considered, with different types of fuel and different maintenance costs. (A rural location is assumed where piped-in natural gas is unavailable.) The relative fuel cost, utilization efficiency, and maintenance cost of each system will be important in the selection of the most economic system for a particular application.

Slide G8 shows that the lowest-LCC system in this example is the oil furnace. Note that the SIR is lower for the oil furnace than for the heat pump. This shows that the **overall** SIR, computed for **total** savings and investment costs, is not a good indicator of the optimal design for a particular system. But in this case, the **incremental** SIR for the additional investment ($500) required for the oil furnace is greater than 1.0 (to be exact: 1.55 = $772/$500). In other words, while the oil furnace/CAC system costs $500 more than the heat pump system, it provides an additional reduction of $772 in present-value energy and OM&R costs, reducing its LCC below that of the heat pump.

SIMULTANEOUS OPTIMIZATION
OF INTERDEPENDENT SYSTEMS

Interaction among systems   Slides G9 and G10
Determining the optimal design or efficiency for a number of interdependent systems within a building generally requires a **simultaneous analysis to properly account for the interaction among the systems.** The interaction results when the specification of one system affects the savings from other systems. For example, as the thermal envelope of the building becomes tighter (i.e., more insulation and more efficient window systems are employed), the savings from improvements in the heating/cooling system diminish, making these improvements less cost effective. Similarly, as the efficiency of the heating/cooling system is increased, the savings from envelope improvements diminish, making these improvements less cost effective. And some of the interactions among systems have stronger effects on savings than others.

The best overall combination of building system specifications is the combination with the lowest LCC. While this is straightforward, the number of potential combinations can be very large and thus costly to evaluate.

In general, only practical and balanced combinations of alternatives need to be considered. Thus it is unlikely that a low level of attic insulation and a high level of window glazing improvements would be used together. Try to eliminate as many unlikely combinations as possible before performing an energy analysis on the remaining combinations. The **energy analysis** of the building is the costly part of the simultaneous analysis; the **economic analysis** can generally be performed quickly once the energy consumption for each combination of alternatives is known.

Strategies for simultaneous optimization   Slide G11
A good way to find a starting point for the optimization process is to find the lowest-LCC efficiency level or the lowest-LCC design alternative for each system, holding the other systems at the "best guess" level. Then determine the sensitivity of the various systems to changes in other systems and to changes in energy prices to get an idea of the stability of the optimal specification for each system. In general, the interaction among envelope components has a relatively weak effect, while the interaction between the envelope and the HVAC system has a relatively strong effect. Reducing the overall load on the HVAC system by improving the envelope is similar to lowering energy prices in terms of its effect on the optimal HVAC system design (i.e., the energy savings from improving the HVAC system become smaller as the loads are reduced). Improving the efficiency of the HVAC system is similar to reducing energy prices in terms of its effect on the optimal envelope specifications. Keep in mind that as energy prices are reduced, the optimal investment level in an energy-related building system is generally the same or lower, but not higher, and vice versa.

Example

Slide G12 provides an example of the combined LCC for three systems:

> Attic insulation: R-0, R-11, R-19, R-30, and R-38;
> Window glazing: 1, 2, and 3 panes; and
> Furnace efficiency: 75 percent and 85 percent

There are a total of 30 possible combinations (5x3x2) of alternatives. But the number of practical and balanced combinations needed for the analysis is much smaller. Starting with best guesses of R-30 insulation, 2-pane glazing, and 75 percent furnace efficiency, we would find that--without examining the interactive effects--the R-30 insulation, 3-pane glazing, and 75 percent furnace efficiency would each be best. The interactive analysis can then be conducted for combinations close to these individual optima. In this example, the combination with the lowest LCC overall--found after examining all combinations close to this one--turns out to be the combination of R-30 attic insulation, 3-pane glazing, and a 75 percent furnace efficiency.

When trying out combinations close to the one that is based on a best guess, you should use your engineering experience to decide whether **low levels** of system interaction are significant enough to warrant additional computations. Energy savings obtained from computer simulations of interactions between systems are not always accurate enough to justify fine-tuning an LCC decision.

EXERCISE G1
Use LCC and NS to Choose Among Single-, Double-, and Triple-Glazed Windows

	Purchase & Installation Cost ($)	Δ Cost ($)	Annual Heating Load (MBtu)	Δ Annual Heating Load (MBtu)
Single-Glazed Windows	2,000	2,000	60	
Double-Glazed Windows	2,800	800	50	-10
Triple-Glazed Windows	3,400	600	48	-2

Furnace efficiency: 0.75

Fuel: Distillate Oil

Initial Price of Oil: $1.12/gallon (=$8.00/MBtu) (commercial pricing)

Location: Vermont

Type of Building: Park Service, Ranger's House

Estimated Life: Indefinite

ALLOCATING INVESTMENT FUNDING AMONG COMPETING PROJECTS

MODULE H   Lecture, Discussion, Exercises

Objectives

At the conclusion of this module, you will be able to

- Use the SIR method to allocate a budget among independent projects

- Allocate a budget among projects with mutually exclusive alternatives

Determining Project Priority
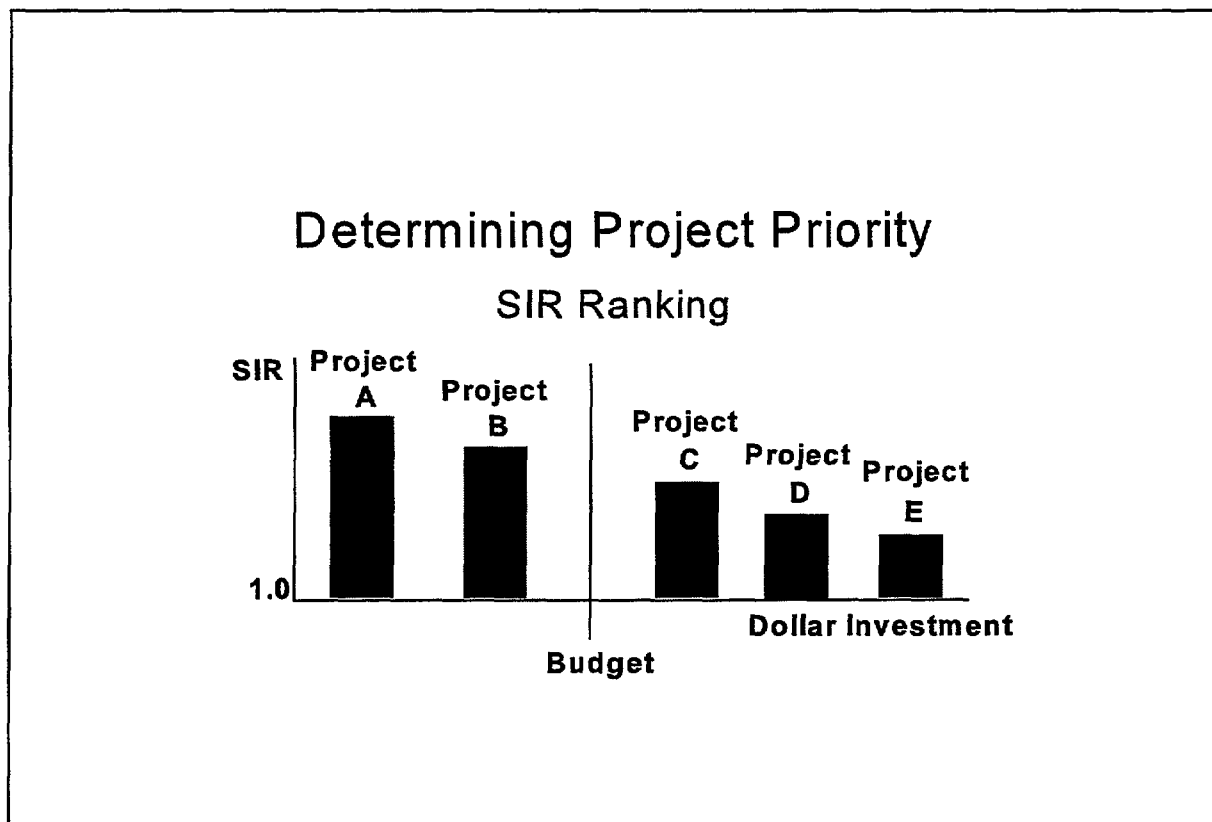
Slide H1

NOTES:

Determining Project Priority

Ranking Independent Projects

Assumptions

Project	I	MBtu Saved	PV Energy Savings
A	$10,000	100	$20,000
B	10,000	1,000	17,000
C	5,000	200	11,000
D	5,000	220	11,500

Budget = $20,000

NOTES:

Determining Project Priority

Ranking Independent Projects

By Btu / I

Project	I	MBtu Saved	MBtu / $1,000	Rank
A	$10,000	100	10	4
B	$10,000	1,000	100	1
C	$5,000	200	40	3
D	$5,000	220	44	2

NOTES:

Determining Project Priority

Ranking Independent Projects

By Net Savings

Project	I	PV Energy Savings	NS	Rank
A	$10,000	$20,000	$10,000	1
B	10,000	17,000	7,000	2
C	5,000	11,000	6,000	4
D	5,000	11,500	6,500	3

NOTES:

Determining Project Priority   Slide H5

Ranking Independent Projects

By SIR

Project	I	PV Energy Savings	SIR	Rank
A	$10,000	$20,000	2.0	3
B	10,000	17,000	1.7	4
C	5,000	11,000	2.2	2
D	5,000	11,500	2.3	1

NOTES:

Determining Project Priority

Ranking Independent Projects

Comparison of Net Savings
from Ranking by Btu / I, NS, and SIR

	Btu / I	NS	SIR
		A (10,000)	A (10,000)
	B (7,000)	B (7,000)	
	C (6,000)		C (6,000)
	D (6,500)		D (6,500)
Total NS:	**$19,500**	**$17,000**	**$22,500**

NOTES:

Determining Project Priority

Ranking Independent Projects

By SIR

Projects	First Cost ($1,000)	PV Energy Savings (1,000)	Net Savings (1,000)	SIR	SIR Ranking
A	$ 200	$ 900	$ 700	4.5	7
B	2,000	10,000	8,000	5.0	6
C	1,600	12,000	10,400	7.5	5
D	10,000	80,000	70,000	8.0	4
E	2,000	25,000	23,000	12.5	1
F	3,000	36,000	33,000	12.0	2
G	1,000	9,000	8,000	9.0	3
	$19,800				

NOTES:

Determining Project Priority

Selecting Projects
For a Budget of $10,000

Project	First-Cost	Net Savings
Option 1 -- accept all projects except D:		
E	$2,000	$23,000
F	3,000	33,000
G	1,000	8,000
C	1,600	10,400
B	2,000	8,000
A	200	700
Total	$9,800	$83,100
Option 2 -- accept only project D:		
D	$10,000	$70,000

NOTES:

Combining Allocation/Sizing Decisions

Allocating Investment Funds Among Projects with Different Alternatives

Project Alternatives	First Cost ($)	PV Savings ($)	NS ($)
A	$12,000	60,000	$48,000
B(1)	5,000	15,000	10,000
B(2)	6,000	17,000	11,000
C	1,000	3,000	2,000
D	3,000	12,000	9,000
E	8,000	12,000	4,000
F	5,000	14,500	9,500

NOTES:

Combining Allocation/Sizing Decisions

Ranking Projects with Different Alternatives
By Incremental SIR

Projects	I ($)	Savings ($)	NS ($)	Δ SIR	Priority
A	12,000	60,000	48,000	5.0	1
B(1)	5,000	15,000	10,000	3.0	3
B(1)→B(2)	1,000	2,000	1,000	2.0	6
C	1,000	2,500	1,500	2.5	5
D	3,000	12,000	9,000	4.0	2
E	8,000	12,000	4,000	1.5	7
F	5,000	14,500	9,500	2.9	4

NOTES:

Combining Allocation/Sizing Decisions

Selecting Projects for a
One-time Budget of $20,000

Select	I	NS
A	$12,000	48,000
D	3,000	9,000
B(1)	5,000	10,000
	$20,000	$67,000

NOTES:

Combining Allocation/Sizing Decisions

Slide H12

Selecting Among Projects with Predetermined Optimal Efficiency or Design

Projects	I	Savings	NS	SIR	Priority
A	$12,000	$60,000	$48,000	5.0	1
B(2)	6,000	17,000	11,000	2.8	4
C	1,000	2,500	1,500	2.5	5
D	3,000	12,000	9,000	4.0	2
E	8,000	12,000	4,000	1.5	6
F	5,000	14,500	9,500	2.9	3

For a budget of $20,000 when future funding is anticipated:

Select	I	NS
A	$12,000	$48,000
D	3,000	9,000
F	5,000	9,500
	$20,000	$66,500

NOTES:

H-13

DETERMINING PROJECT PRIORITY

Usefulness of SIR for Assigning Project Priority   Slide H1

The Savings-to-Investment Ratio (SIR) is useful for assigning priority to cost-effective projects when the budget is limited.[1] **Selecting projects in descending order of their SIRs can be relied on to maximize total net savings for the budget**, provided the budget can be fully expended without departing from the SIR ranking.

Slide H1 depicts how projects are ranked in descending order of their SIRs and selected until the budget is exhausted.

The **LCC and NS methods are NOT appropriate for assigning funding priority** to individual projects. It may seem a paradox that assigning highest priority to projects with the greatest individual net savings will usually <u>not</u> maximize total net savings for the budget. The reason for this is that one project with high first costs may have net savings that are greater than those for any one other project but smaller than those of two or more projects that, taken together, have a lower first cost.

Furthermore, assigning higher priority to **projects with the greatest Btu savings** per investment dollar (Btu/I) **will usually NOT maximize total net savings** for the budget. The Btu/I measure treats all Btu as equal, ignoring that it is more economic to save expensive electricity Btu in New York City than inexpensive coal Btu in Ohio.

Example   Slides H2 to H6

Slide H2 gives investment cost, annual quantity of energy savings, and present-value energy savings for four independent projects, A, B, C, and D. Project A saves electricity in New York City. Project B saves coal in West Virginia. Project C saves natural gas in Iowa. Project D saves distillate oil in Alaska.

Slides H3, H4, and H5 show project ranking by Btu/I, by NS, and by SIR. Note that the rankings are different for each of the three methods. Slide H6 compares the **total net savings** resulting from each of the three rankings, assuming a total budget of $20,000. The comparison shows that ranking by SIR gives higher total net savings ($22,500) than ranking either by Btu/I ($19,500) or by NS ($17,000).

---

[1]The Adjusted Internal Rate of Return (AIRR) is also appropriate for assigning priority to cost-effective projects when the budget is limited. It may be used as an alternative ranking method.

LIMITATIONS OF SIR FOR ASSIGNING PRIORITY

"Lumpiness" in project costs may make it impossible to fully exhaust the budget by taking projects exactly in descending order of their SIRs. In this case, ranking by SIR may fail to identify the group of projects which will maximize overall net savings for the budget. It is then necessary to depart from the SIR ranking to fully allocate the budget; **a comparison of total NS of the various possible combinations of projects must be made** to ensure that the combination which maximizes net savings is selected. Any funds left uninvested are assumed to earn a rate of return equal to the discount rate, i.e., the rate of return of the next best investment opportunity, and hence add nothing to net savings.

Example   **Slides H7 and H8**

Slide H7 lists initial investment costs, present-value savings, net savings, SIR, and SIR ranking for seven independent projects, A through G. Project costs total nearly $20,000. Assume the available budget is only $10,000. According to the SIR ranking

> Project E (SIR = 12.5) is first chosen for an expenditure of $2,000.
> Project F (SIR = 12.0) is chosen next for an expenditure of $5,000.
> Project G (SIR = 9.0) is chosen for an expenditure of $1,600.
> Project D (SIR = 8.0), is the next ranked project with $10,000,

but its cost drives total cost over the available budget. The options are to

> (1) take projects E, F, and G, skip over project D, and take the remaining projects C, B, and A, or
>
> (2) drop projects E, F, and G, and take only project D.

Slide H8 compares total net savings of option 1 ($83,100) and option 2 ($70,000), and finds the net savings of option 1 to be higher and hence preferable.

COMBINING ALLOCATION/SIZING DECISIONS   **Slides H9 to H12**

To maximize total net savings from an investment in a group of projects **where some have alternative levels of efficiency or alternative designs**, the budget allocation can be undertaken in two distinct ways:

(1) *When there is a limited budget and no future funding anticipated:*
Calculate the **incremental SIR (ΔSIR) for each additional level of investment** associated with any project that has more than one alternative, and rank the incremental investments as though they were separate projects.

(2) *When there is no budget limitation or when future funding is anticipated:*
Determine the lowest-LCC efficiency level or design alternative for the relevant project(s) **before** computing the SIR for ranking purposes.

Slide H9 lists present-value savings and net savings for six independent projects, A through F. One of the projects, project B, can be done either at a lower level of efficiency, designated B(1), or at a higher level of efficiency, designated B(2). Level B(2) costs $1,000 more than level B(1) and saves $2,000 more, which means that its net savings are $1,000 higher than those of level B(1). If there is no budget limitation, clearly it pays to choose the higher-efficiency model B(2) over the lower-efficiency model B(1). But if there is a budget constraint, the extra investment for B(2) may be less worthwhile than a competing use of funds.

Example 1. Limited budget and no future funding

Slide H10 ranks the projects by **incremental SIR**. The increment to project B (designated B(1) → B(2)) ranks sixth. For a budget of $15,000, projects A and D are chosen. For a budget of $20,000, projects A, D, and B at its lower efficiency level B(1) are chosen. For a budget of $25,000, project F is added. Only when the budget reaches $27,000 is increment B(1)→B(2) included in the budget.

Slide H11 shows that the combined budget allocation/sizing for a budget of $20,000 results in net savings of $67,000. If F were included instead of B(1)--as would be the case if the projects had been ranked by **total SIR** as in slide H12--net savings would amount to $66,500, a lower amount than the net savings obtained from the joint allocation/sizing solution.

Example 2. Future funding anticipated

In slide H12, project B is ranked fourth by **total SIR** and would not be included in this year's budget of $20,000 but will be done--at the optimal efficiency level--when additional funding becomes available.

Conclusions

- When there is a **one-time budget** to be allocated, it is better to make **increments** in levels of efficiency or design alternatives compete for funding. In this case, use the **incremental SIR** (**ΔSIR**) for ranking. The problem with this approach is that the additional increments that would be cost-effective now if funding were available are not likely to ever be implemented later if the funding does become available.

- When **additional funding** is anticipated, it is better, as a rule, to predetermine the optimal level of efficiency or the optimal design alternative as though there were no budget limitation. Then let those projects, ranked by **total SIR**, compete for funding as it becomes available. This approach allows projects to be implemented at their most cost-effective level from an LCC standpoint, deffering less cost-effective projects until the additional funding is received.

EXERCISE H1
Allocating a Budget among Projects Using the SIR

Allocate a budget of $6,500 among the following projects, assuming that no future funds will be available for retrofitting Buildings A, B, C, and D.

Energy Conservation Projects	First Cost ($)	PV Savings ($)
Add Solar Water Heater in Building A	2,000	3,800
Replace Chillers in Building A	12,000	16,800
Add R-8 Insulation in Building B	1,000	5,000
Increase Insulation in Building B from R-8 to R-19	500	1,000
Increase Insulation in Building B from R-19 to R-30	500	600
Replace Lighting System in Building C	3,000	9,000
Replace Windows in Building D	6,000	9,600

What if the budget were $7,000?

USING THE BLCC QUICK INPUT PROGRAM (QI)

MODULE I   Lecture, Discussion, Exercises

Objectives

At the conclusion of this session, you will be able to

- Run the BLCC QI computer program (QI2)

- Set up and solve a lowest-LCC problem using QI2

- Compute measures of economic performance for
  a project alternative

Slide I1

BLCC "Quick Input" Module

- ■ LCC analysis of multiple project alternatives
- ■ Consistent with BLCC
- ■ Limited data entry
- ■ Common assumptions included in header data
- ■ Project alternatives included as line items
- ■ LCC calculated for all alternatives at once
- ■ BLCC files generated for selected alternatives

NOTES:

Instructions for using QI are in section 6 of the BLCC User's Guide.

Slide I2

Main Quick Input Menu

Create New QI file
Edit Existing QI file
Print QI Input file
LCC Calculations
Generate BLCC Input files
Setup
Exit to BLCC
Exit to DOS

NOTES:

Slide I3

Select the type of analysis:

(1) General LCC Analysis - - Non-Federal, No Taxes
(2) Federal Analysis - - Energy Conservation Projects
(3) Federal Analysis - - Projects Subject to OMB A-94
(4) MILCON Design - - Energy Conservation Projects
(5) MILCON Design - - Projects Subject to OMB A-94

NOTES:

Slide I4

FILE HEADER INFORMATION (COMMON DATA)

```
COMMON PROJECT NAME: House Insulation
BASE DATE OF STUDY (YEAR):1996      (e.g., 1993)
SERVICE DATE (YEAR):       1996     (e.g., 1993)
STUDY PERIOD LENGTH (YEARS/MONTHS FROM BASE DATE): 30      (E.G., 20/6)
DISCOUNT RATE:5    %
INFLATION RATE:0    % (0 for constant dollars with real discount rate)


COMMON ENERGY DATA        #1           #2           #3           #4
   ENERGY TYPE CODE:      1            4            0            0
   UNITS CODE:            1            3            0            0
   PRICE PER UNIT:      $.1           $1           $0           $0
   ESCALATION TYPE CODE:  2            2            0            0
```

NOTES:

Energy type codes: 1=Elec; 2=Dist Oil; 3=Resid Oil; 4=Nat Gas; 5=LPG; 6=Coal;
                         7=Central Steam; 8=Chilled Water; 9=Other
Unit codes: 1=kWh; 2=gallon; 3=therm; 4=MBtu; 5=pound; 6=MJ;
                         7=GJ; 8=Liter; 9=kg
Energy Esc. type codes: 1=user rates; 2=DOE rates; 3=user modifies DOE rates

Slide I5

QI Calculation Rule Options

```
Compute residual value* for initial capital investment if project life
extends beyond end of study period (Y/N)? Y

Compute residual value* for any capital replacement whose life extends
beyond end of study period (Y/N)? Y

Include capital replacements and residual values as investment-related
costs for computation of SIR and AIRR** (Y/N)? Y
```

NOTES:

Residual values are calculated as the ratio of remaining life to total life, times the intial cost, and then adjusted for inflation.

Slide I6

Input Data for Project Alternatives (left side)

ALT #	ALTERNATIVE NAME	GROUP CODE	LIFE (Y/M)	INITIAL COST($)	CAPITAL REPLACEMENTS FREQ*	CAPITAL REPLACEMENTS COST($)	ANNUAL OM&R COST($)	NON-ANNUAL FREQ*	NON-ANNUAL COS
1	R-0 attic	A	30/0	0	0/0	0	0	0/0	0
2	R-11 attic	A	30/0	425	0/0	0	0	0/0	0
3	R-19 attic	A	30/0	625	0/0	0	0	0/0	0
4	R-30 attic	A	30/0	925	0/0	0	0	0/0	0
5	R-38 attic	A	30/0	1125	0/0	0	0	0/0	0
6	R-49 attic	A	30/0	1425	0/0	0	0	0/0	0
7	no strm door	B	0/0	0	0/0	0	0	0/0	0
8	storm door	B	15/0	150	15/0	130	0	7/6	20
9	single glass	C	30/0	2000	0/0	0	100	0/0	0
10	double glass	C	30/0	2500	15/0	300	125	5/0	100
11	triple glass	C	30/0	3000	15/0	400	150	5/0	100
12									

NOTES:

Screen display must be scrolled to right to access energy variables on same line; scroll downward if more than 12 alternatives are to be included.

Replacement costs and non-annul OM&R costs are automatically repeated at the frequency entered until the end of the study period. BLCC input files generated by QI include these multiple replacements and non-annual OM&R costs.

F1=Insert Row, F2=Delete Row.
Press <PgDn> when entry is complete.

Slide I7

Input Data for Project Alternatives (right side)

ALT #	CAPITAL REPLACEMENTS FREQ*	COST($)	ANNUAL OM&R COST($)	NON-ANNUAL OM&R FREQ*	COST($)	ANNUAL ENERGY USE ELECTRIC (kWh) ---#1---	NAT.GAS (therm) ---#2---	AN. ELEC. DEMAND CHARGE($)
1	0/0	0	0	0/0	0	1465	625	0
2	0/0	0	0	0/0	0	1231	465	0
3	0/0	0	0	0/0	0	1177	440	0
4	0/0	0	0	0/0	0	1138	420	0
5	0/0	0	0	0/0	0	1123	415	0
6	0/0	0	0	0/0	0	1109	410	0
7	0/0	0	0	0/0	0	1465	625	0
8	15/0	130	0	7/6	20	1460	620	0
9	0/0	0	100	0/0	0	1465	625	0
10	15/0	300	125	5/0	100	1400	550	0
11	15/0	400	150	5/0	100	1380	525	0
12								

NOTES:

I-8

Slide I8

Saving Input Data Filename

Enter filename for saving Quick Input Data File: ░░░░░░ .QI

NOTES:

If default name is shown, press <Enter> to accept default name.

Slide I9

Main Quick Input Menu

Create New QI file
Edit Existing QI file
Print QI Input file
LCC Calculations
Generate BLCC Input files
Setup
Exit to BLCC
Exit to DOS

NOTES:

Slide I10

BLCC Data File Generator

Generated BLCC data file names will be of form 'AAAAAxxx.DAT',
where AAAAA = common filenames, and
xxx = digits corresponding to record number.

Enter common filename: test

NOTES:

Newly generated files will replace old files with same name.

```
BLCC Quick Input Program (QI2.2-96)    12-06-1995/12:34:00

QI filename =  DEMO.QI
Analysis type = General LCC Analysis--Non-Federal, No Taxes
Project name = House Insulation
Base date of study = 1996
Service date =      1996
Study Period = 30 years
Discount rate =  5.0%
Annually recurring costs and energy costs discounted from end of year.
DOE energy price escalation rate file = ENCOST96

Number of alternatives in file = 11
Number of groups in file = 3

Note: Project alternatives displayed in increasing order of investment cost

   Group code: A     ----------------Present-Value Costs----------------
   Alternative       Investment     OM&R         Energy      Total Life-
     Name            Costs*         Costs        Costs       Cycle Costs
   -----------       ------------   -----------  ----------- ------------
   R-0 attic                  $0           $0      $13498       $13498
   R-11 attic               $425           $0      $10265       $10690
   R-19 attic               $625           $0       $9733       $10358
   R-30 attic               $925           $0       $9313       $10238<--MIN LCC
   R-38 attic              $1125           $0       $9200       $10325
   R-49 attic              $1425           $0       $9088       $10513

Comparative measures are only calculated for the alternative with lowest
LCC relative to alternative with the lowest present-value investment cost.

Comparative economic measures for R-30 attic relative to R-0 attic:
NET SAVINGS =         $3260;  SIR =  4.52;  AIRR = 10.42%
Ratio of present-value energy savings to total savings =  1.00

* Investment costs include capital replacements and residual values (if any).
  Residual values for initial capital investment are calculated when life
  extends beyond end of study period.
  Residual values for capital replacements are calculated when life extends
  beyond end of study period.


   Group code: B     ----------------Present-Value Costs----------------
   Alternative       Investment     OM&R         Energy      Total Life-
     Name            Costs*         Costs        Costs       Cycle Costs
   -----------       ------------   -----------  ----------- ------------
   no strm door               $0           $0      $13498       $13498<--MIN LCC
   storm door               $213          $30      $13401       $13643

Comparative measures are only calculated for the alternative with lowest
LCC relative to alternative with the lowest present-value investment cost.

Can't compute comparative economic measures for an alternative against itself.

* Investment costs include capital replacements and residual values (if any).
  Residual values for initial capital investment are calculated when life
  extends beyond end of study period.
  Residual values for capital replacements are calculated when life extends
  beyond end of study period.


   Group code: C     ----------------Present-Value Costs----------------
   Alternative       Investment     OM&R         Energy      Total Life-
     Name            Costs*         Costs        Costs       Cycle Costs
   -----------       ------------   -----------  ----------- ------------
   single glass            $2000        $1567      $13498       $17066
   double glass            $2644        $2177      $12053       $16874<--MIN LCC
   triple glass            $3192        $2561      $11574       $17328

Comparative measures are only calculated for the alternative with lowest
LCC relative to alternative with the lowest present-value investment cost.
```

```
Comparative economic measures for double glass relative to single glass:
NET SAVINGS =          $191;  SIR =  1.30;  AIRR =  5.91%
Ratio of present-value energy savings to total savings =  1.00

* Investment costs include capital replacements and residual values (if any).
  Residual values for initial capital investment are calculated when life
  extends beyond end of study period.
  Residual values for capital replacements are calculated when life extends
  beyond end of study period.
```

Slide I11

Tag desired alternatives for generating BLCC input files

Group/Alternative		LCC	File Name
A:	R-0	$17466	test1.DAT
A:	R-11	$14264	test2.DAT
A:	R-19	$13487	test3.DAT
A:	R-30	$13148	test4.DAT
A:	R-38	$13157	test5.DAT
B:	Window1	$19405	test6.DAT
B:	Window2	$15635	test7.DAT
B:	Window3	$15452	test8.DAT

NOTES:

Use cursor to select alternatives; toggle space bar to tag (untag) file.
Press <Enter> when finished; <Esc> to back up.

EXERCISE I1
COMPUTER LAB #2
Quick Input Analysis of Attic Insulation and HVAC System

Part 1. Selection of Optimal Attic Insulation

Use Quick Input to determine the level of insulation with the lowest LCC in the attic of an existing house located in central Maryland. The existing insulation level is R-11.
Use the following project-related data:

Base date: 1996
Service date: 1996
Study Period: 25 years
Electricity cost: $.075/kWh
Type of study: General, constant dollars
Discount rate: 4%, real
Energy Price Escalation rates: Use DOE rates, residential, MD
No resale/residual value

Attic insulation cost and resulting kWh usage:

Total Level	Installed Cost	Annual KWh
R-11	n/a	12,000
R-22	$500	10,000
R-30	$675	9,300
R-41	$900	9,000
R-49	$1,075	8,825

Part 2. Simultaneous Selection of Attic Insulation and HVAC System

In addition to installing additional attic insulation, a new heat pump system is being considered for replacement of the existing electric furnace and central air conditioning unit in the same house. Since the heating and cooling system and the attic insulation are functionally interdependent, they must be evaluated simulataneously. Only two levels of insulation are being considered in this example: adding R-30 or R-38 over the existing R-11, for totals of R-41 and R-49. Use the project-related data from part 1 and the following data schedule to determine the most cost effective combination of attic insulation and heating/cooling system:

	existing system	heat pump
Annual kWh usage:		
raise attic insul to R-41	9000 kWh	4500 kWh
raise attic insul to R-49	8825 kWh	4425 kWh
Initial cost:		
R-41	$900	$3900
R-49	$1075	$4075
Annually recurring O&M cost:		
R-41 and R-49	$100	$200

Compressor replacement at 10-year intervals (enter as non-annual O&M cost):
R-41 and R-49	$600	$800

Remember that since only one of the four combinations can be selected, all four must be given the same group code.

DEALING WITH UNCERTAINTY AND RISK IN LCC ANALYSIS

MODULE J   Lecture, Discussion, Exercises

Objectives

At the conclusion of this session, you will

- be able to determine which input variables are critical

- be able to perform sensitivity analysis and breakeven analysis

- be acquainted with probabilistic techniques of uncertainty assessment

Techniques for Dealing with Uncertainty

Deterministic Techniques:
- Sensitivity Analysis
- Breakeven Analysis
- Input estimate using expected values

Probabilistic Techniques:
- Input estimate using probability distributions
- Monte Carlo simulation

NOTES:

Deterministic Techniques   Slide J2

Sensitivity Analysis is Performed - -

by repeating an economic evaluation

with one or more input values changed.

NOTES:

Deterministic Techniques

Sensitivity Analysis Answers the Following Questions:

1. **Which of the input values, if changed, would have the greatest effect on analysis results ?**

2. **What effect would changes in the input values have on the range of analysis results ?**

3. **What would happen if this or that input value were different ?**

NOTES:

Deterministic Techniques

Sensitivity Analysis
Identify Critical Inputs
(Heat Pump Alternative)

10% Change in Input Value	Change in LCC	
	in $	in %
Annual energy cost $902	$916	+7%
Investment $3,300	$300	+2%
OM&R $110 + $660	$155	+1%
Salvage value $270	-$17	-0.01%

NOTES:
Sensitivity Analysis based on the following data:
Discount rate: 4%
Study period: 15 years

Input values for Heat Pump:

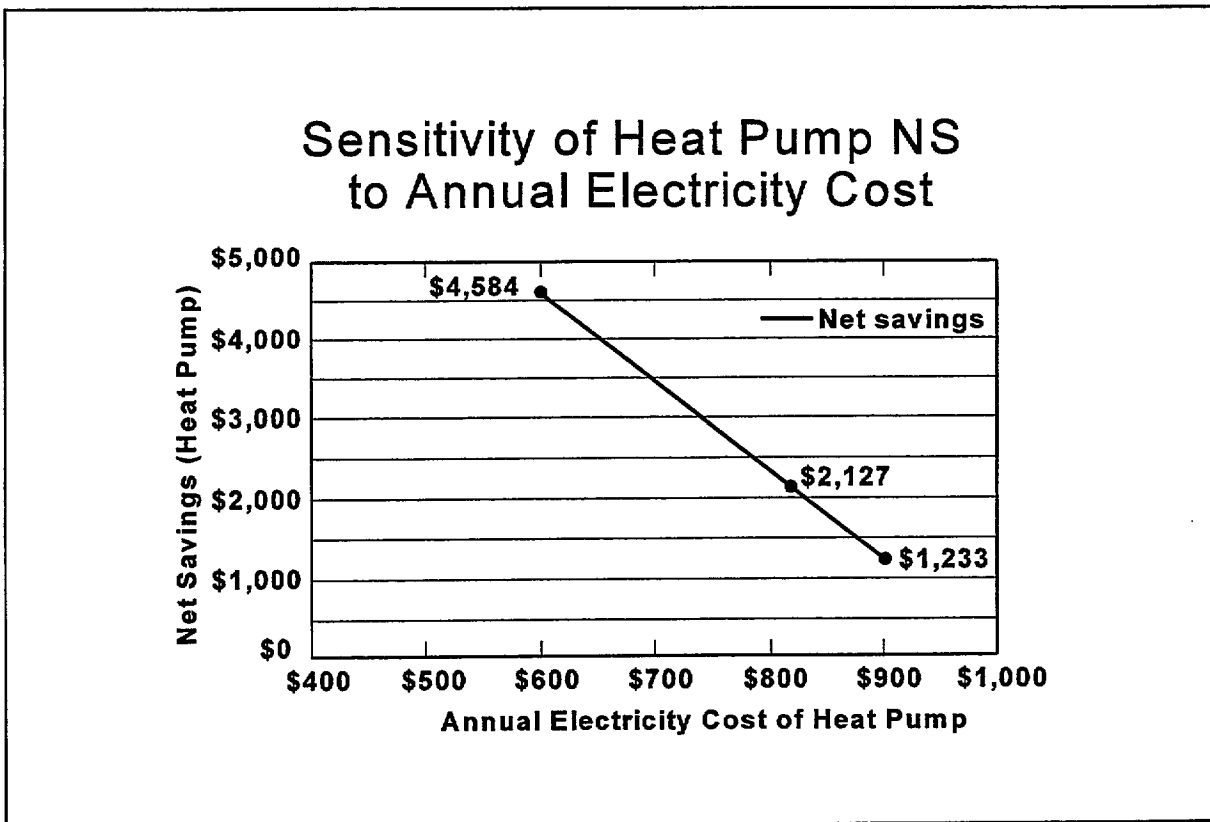|	
Purchase and installation costs:	$3,000
Residual value:	$300
Annual electricity cost:	$820
Annual O&M costs:	$100
Repair cost in year 8:	$600

LCC for baseboard/AC system: $15,668
LCC for Heat Pump: $13,541
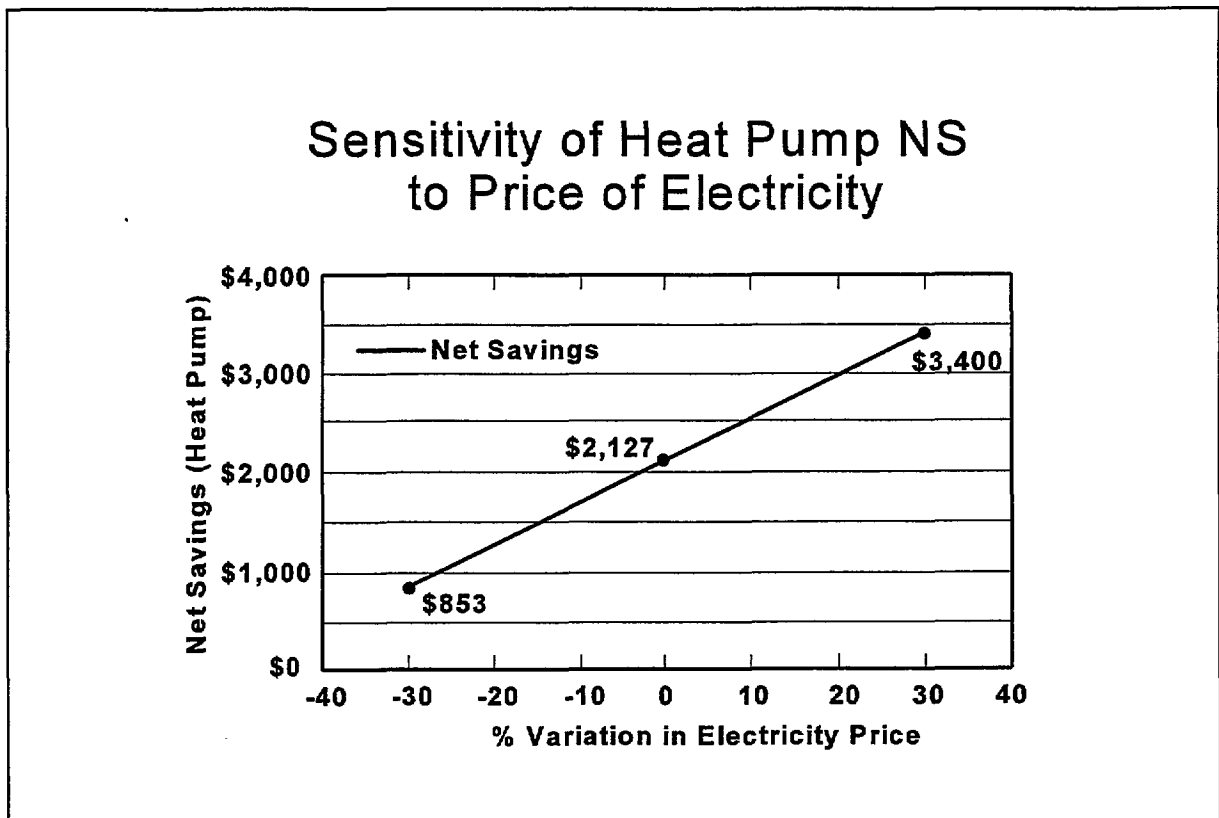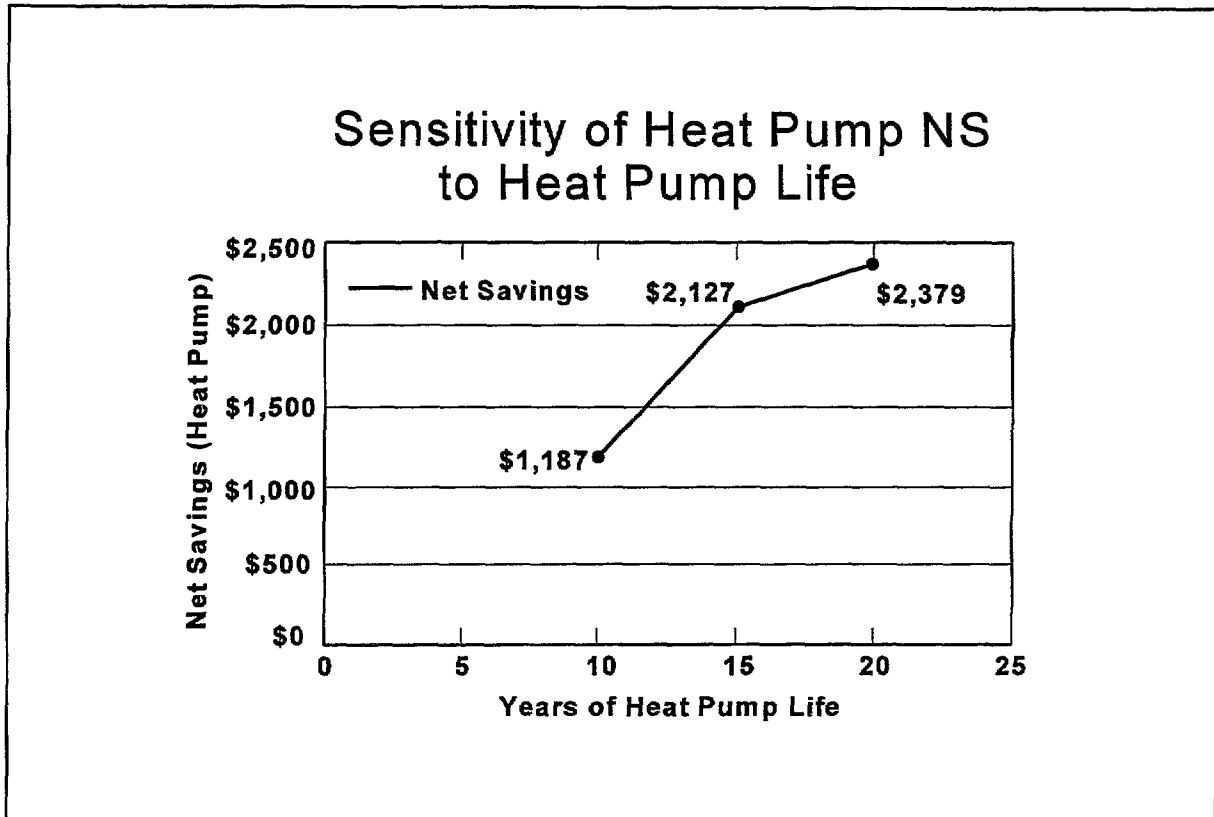NS for Heat Pump: $2,127

Deterministic Techniques

Sensitivity of Heat Pump NS to Annual Electricity Cost

NOTES:

Deterministic Techniques

Sensitivity of Heat Pump NS to Price of Electricity

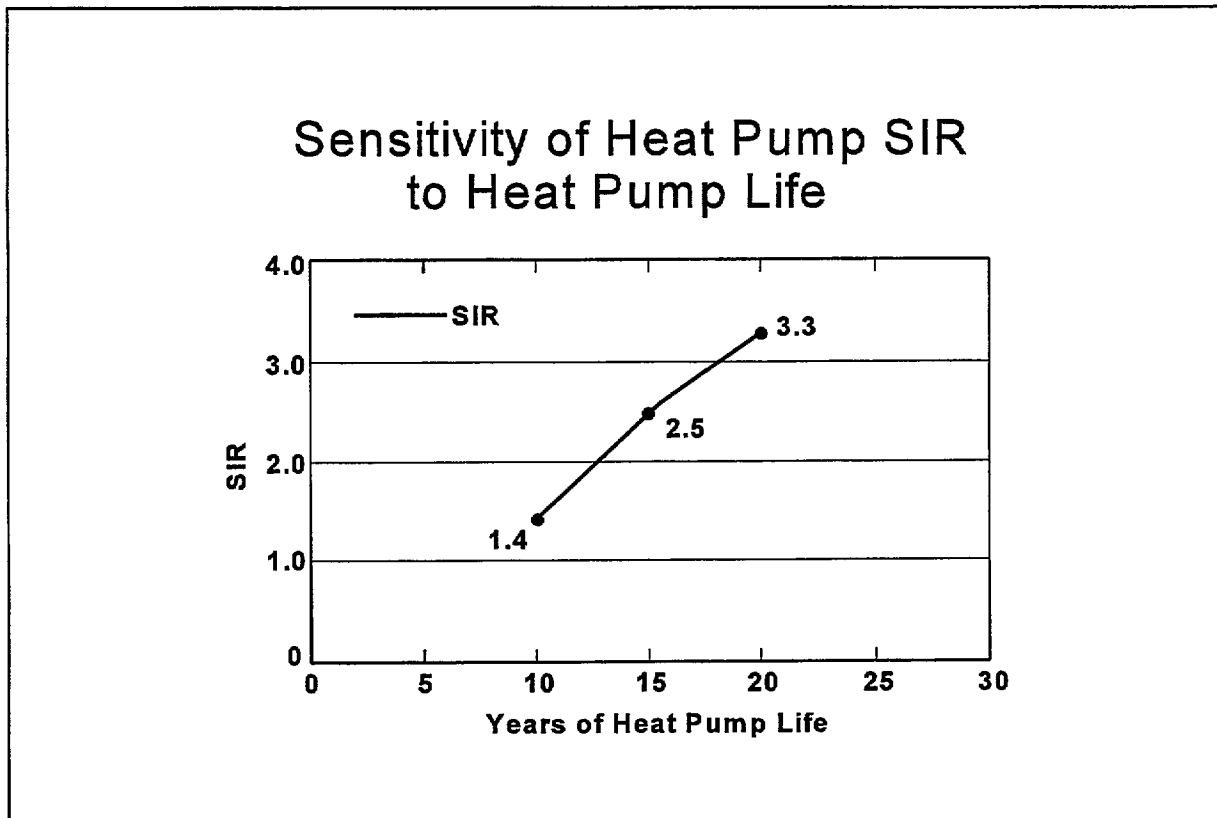NOTES:

Deterministic Techniques

Sensitivity of Heat Pump NS to Heat Pump Life

NOTES:

Deterministic Techniques

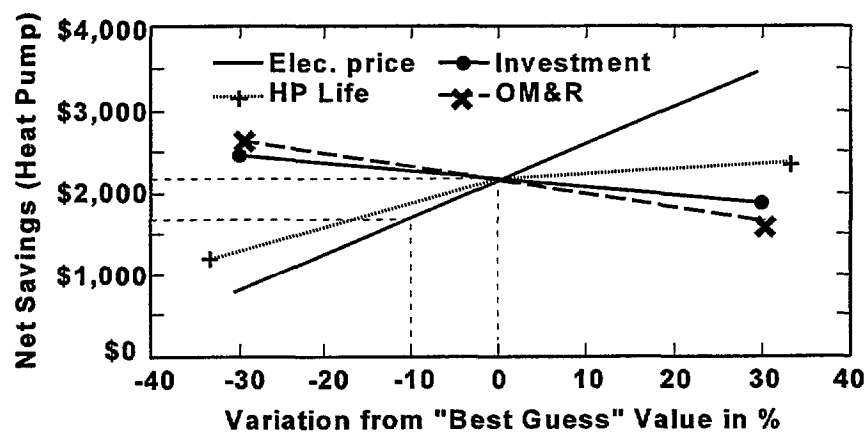NOTES:

Deterministic Techniques

Sensitivity of Heat Pump NS to Uncertain Input Values

NOTES:

Deterministic Techniques Slide J10

<div style="border:1px solid black; padding:1em">

Breakeven Analysis
Heat Pump Alternative

PV Energy Savings   **$4,542**

PV Add'l. Investment   **$1,500**

PV Add'l Residual Value   **$84**

PV Add'l OM&R Costs   **$556 + $146**

PV Savings = PV Costs

- **Breakeven value for Investment, ΔI:**

    4,542 = ΔI + 556 + 146 - 84

    ΔI **= 4,542 - 556 - 146 + 84**

    ΔI **= $3,924**

- **Breakeven value for ΔOM&R**

    ΔOM&R = 4,542 - 1,500 + 84

    ΔOM&R = $3,126

</div>

NOTES:

Deterministic Techniques

Expected-value Estimation of Inputs

$$EV \ = \Sigma \ p(x_i) \ x_i$$

where $p(x_i)$ = the probability of occurrence of x_i

           x_i = the value of x_i

Example: Electricity cost of heat pump

               EV   =   0.20 ($700)

                        =   + 0.50 ($800)

                        =   + 0.30 ($900)

                        = $810

NOTES:

Probabilistic Techniques

Probability Distribution
of Annual Energy Cost for Heat Pump

Mean: $800
Stand. dev. : $100
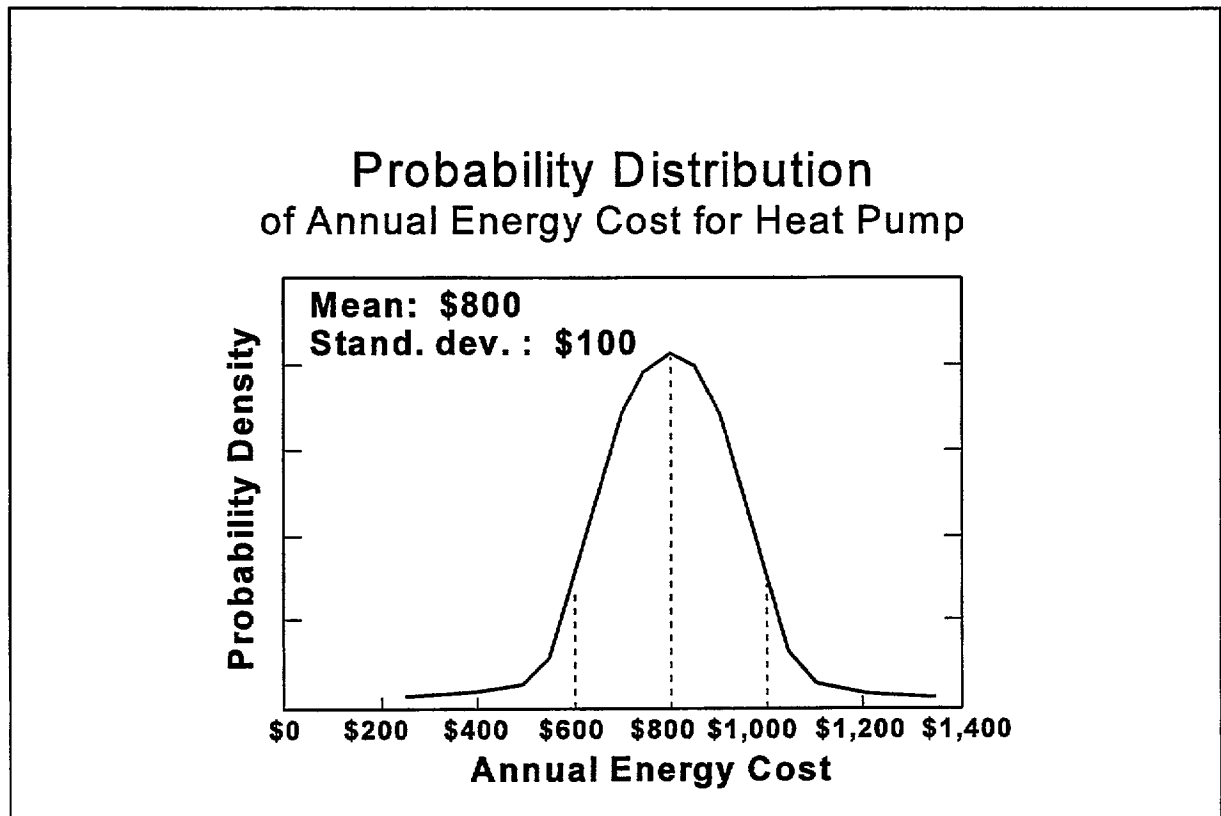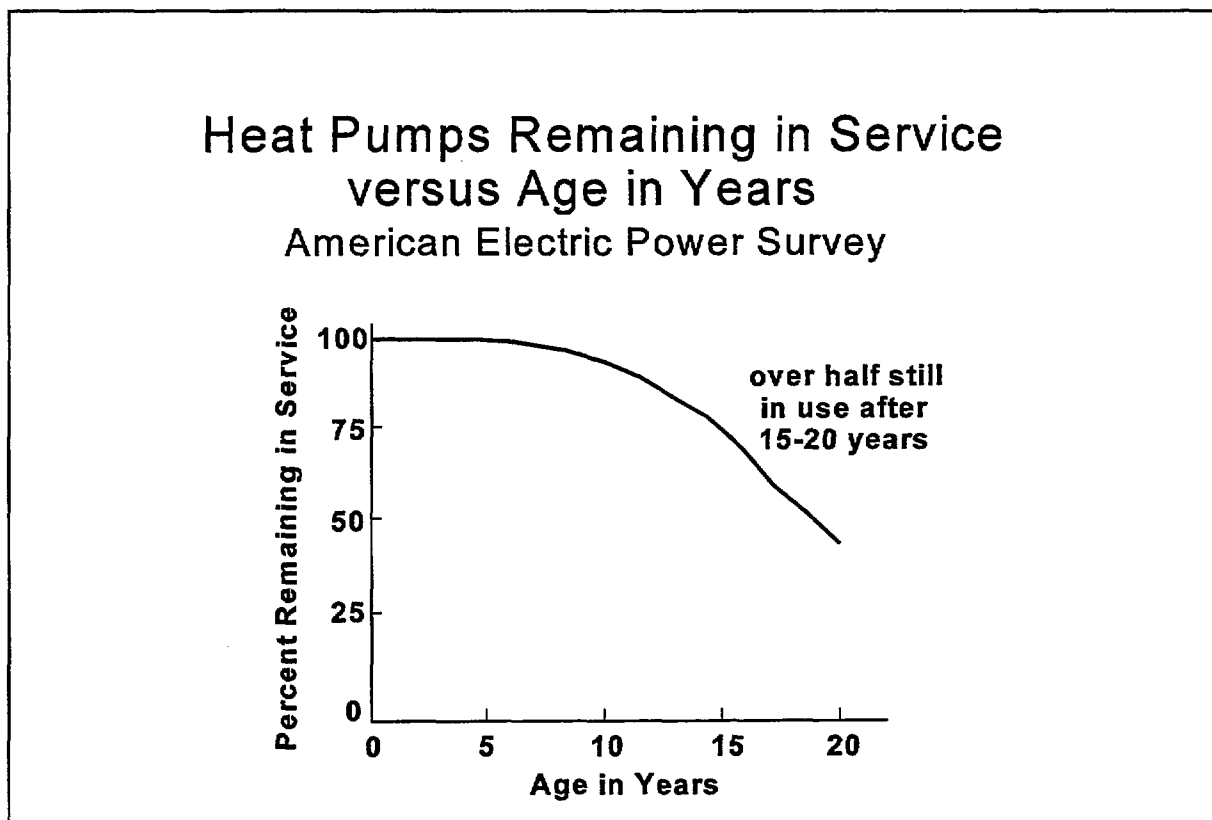
NOTES:

This is a hypothetical probability distribution for annual energy costs.

Probabilistic Techniques   Slide J13

Heat Pumps Remaining in Service versus Age in Years
American Electric Power Survey
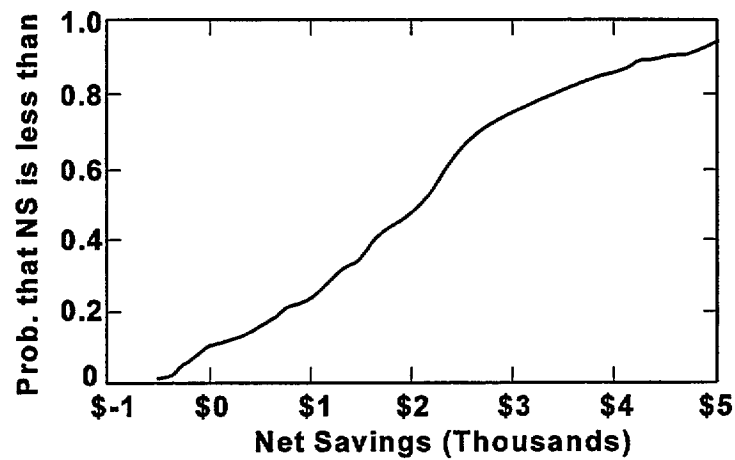

NOTES:

Source: *Heat Pump Reliability*, Electric Power Research Institute, Inc., 1992.

Probabilistic Techniques

Cumulative Distribution Function
of Net Savings for Heat Pumps

NOTES:

This is a hypothetical distribution function.

Probabilistic Techniques

Steps in Performing Monte Carlo Simulation

1. Draw randomly a value for each input variable from its probability function

2. Substitute the set of input values for that round of draws into the measure of worth formula and compute the measure

3. Repeat the process over and over until a probability distribution for the measure of worth can be constructed

4. Generate a cumulative distribution curve for the measure of worth

NOTES:

List of Techniques for Uncertainty Assessment   Slide J16

Techniques That Account for Uncertainty, Risk, or Both

Deterministic

1. **Conservative Benefit and Cost Estimating**

2. **Breakeven Analysis**

3. **Sensitivity Analysis**

4. **Risk-Adjusted Discount Rate**

5. **Certainty Equivalent Technique**

6. **Input Estimate Using Expected values**

Probabilistic

1. **Input Estimate Using Probability Distributions**

2. **Mean-Variance Criterion and Coefficient of Variation**

3. **Decision Analysis**

4. **Simulation**

5. **Mathematical / Analytical Technique**

NOTES:

Adapted from *Techniques for Treating Uncertainty and Risk in the Economic Evaluation of Building Investments*, NIST Special Publication 757, U.S. Dept. of Commerce, NIST, Gaithersburg, MD 20899.

UNCERTAINTY ASSESSMENT IN LCC ANALYSIS   Slide J1

Decisions about energy conservation investments in buildings typically involve a great deal of uncertainty about their costs and potential savings. Performing a life-cycle cost analysis greatly increases the likelihood of choosing an alternative that saves money in the long run. Yet, there may still be some uncertainty associated with the LCC results; life-cycle cost analyses are usually performed early in the design process when only **estimates** of costs and savings are available rather than certain dollar amounts. Uncertainty in input values means that **actual** outcomes may differ from **estimated** outcomes. Uncertainty may cause you to reject cost-effective projects, or accept projects that result in lower net savings than estimated or in net losses. In short, uncertainty in input values creates risk that a decision will have a less favorable outcome than what is expected.

Even though you may be uncertain about some of the input values, especially those occurring in the future, it is still better to include them in an economic evaluation rather than to base your evaluation on first costs only. Ignoring uncertain long-run costs implies the assumption that they are zero, a poor assumption to make.

There are techniques that allow you to estimate the cost of choosing the "wrong" alternative. **Deterministic techniques,** such as **sensitivity analysis** or **breakeven analysis,** are easily performed and do not require a great deal of resources or information. They are called deterministic techniques because they generate single-point estimates of project value. Sensitivity analysis and breakeven analysis recognize that input data are uncertain and examine how this might affect the analysis outcome. But they do not give an **explicit** measure of **risk exposure,** nor do they take into account explicitly a decision maker's or an institution's **risk attitude.**

Probabilistic techniques, on the other hand, quantify risk exposure by deriving probabilities of achieving different values of economic worth (e.g., LCC, NS, SIR) from **probability distributions** for input values that are uncertain. Probabilistic techniques sometimes also include a measure of **risk attitude.** However, they have greater informational and technical requirements than do deterministic techniques. Whether or not you choose them as a method of risk and uncertainty assessment depends on factors such as the size of the project, its importance, and the resources available.

This module focuses on **sensitivity analysis** and **breakeven analysis,** two approaches that are so simple to perform that they should be part of every LCC analysis. Sensitivity analysis is the method recommended by the FEMP rule, and breakeven analysis is often useful as a first screening tool before even performing an LCC analysis. These and a number of other commonly used approaches to risk and uncertainty assessment, both deterministic and probabilistic, are described in greater detail in *Techniques for Treating Uncertainty and Risk in the Economic Evaluation of Building Investments* by Harold E. Marshall, NIST Special Publication 757, September 1988. An introduction to these techniques is presented in a NIST videotape by Harold E. Marshall, entitled *Uncertainty and Risk,* Part II in a Series on Least-Cost Energy Decisions for Buildings, August 1992.

DETERMINISTIC TECHNIQUES

Sensitivity analysis   Slides J2 and J3

Sensitivity analysis measures the **impact on the analysis results of changing one or more key input values** about which there is uncertainty. You simply replace your best-guess estimates, one at a time, or in combinations, with more optimistic or pessimistic values and repeat your calculations. Sensitivity analysis can be performed with respect to any measure of worth (e.g., LCC, NS, SIR, AIRR or PB). In addition, the sensitivity of these measures to a certain input value can be compared among alternatives (e.g., the sensitivity of NS of alternatives A and B to the discount rate).

Sensitivity analysis is useful for determining which of the uncertain input values have the **greatest impact** on a specific measure of economic evaluation. Or, some input values may have a wide range of uncertainty, and sensitivity analysis can help determine how this variability affects the **range** of the measure of worth calculated. The technique is also useful for testing different scenarios to answer **"what if"** questions that may arise during the decision-making process. Having this information increases a decision maker's confidence in life-cycle cost results.

Identifying critical inputs   Slide J4

It is important to know which of the uncertain input parameters are critical because you want to avoid squandering resources gathering additional information on input values that have little effect on LCC results. To identify the critical parameters, simply **increase the value of each of them by a certain percentage** and, holding all others constant, **recalculate the economic measure** to be tested. The higher the percentage change in the outcome for a given change in input value, the greater the effect.

In the baseboard/heat pump example of module D, energy costs have the greatest effect on LCC: a 10 percent increase in the annual energy costs changes LCC by 7 percent, an equal percentage change in OM&R costs changes LCC by only 1 percent. Hence, it would be advisable to work on improving energy cost data before OM&R data.

Estimating the range of results   Slides J5 to J8

To arrive at an estimate of the **upper and lower bounds** of an economic measure, it can be recalculated using the lowest and highest likely estimates of its input variables, corresponding to the most **optimistic** or most **pessimistic** scenarios. The assumption in slide J5 is that the **energy consumption** of the heat pump is uncertain so that the annual cost of energy for the heat pump might be as low as $600 or as high as $900. Net Savings for the heat pump therefore could be as high as $4,584 or as low as $1,233. In this particular case, the range of outcomes indicates that even with the most pessimistic assumption of an annual energy cost of $900, NS would still be positive and the project cost effective.

Slide J6 tests the sensitivity of NS with respect to the **price** of electricity rather than the quantity, so that the annual energy cost would vary both for the baseboard heating system **and** the heat pump.

Depending on whether electricity prices declined or rose by 30 percent from the best-guess estimate, **relative** NS for the heat pump would be as low as $853 or as high as $3,400.

To illustrate that sensitivity analysis can be performed for any input value or any measure of worth, slide J7 estimates the **range of NS** of the heat pump with respect to **system life,** assuming that the heat pump might last only 10 years in a pessimistic scenario or 20 years in an optimistic one.

Slide J8 shows the **range of the SIR**, also with respect to system life. It is intuitively clear that the NS and SIR are higher the longer the service life of the heat pump.

The advantage of depicting these results graphically is that **intermediate** values can be read off easily from the curves and that the **curves can be extended** to the x-axis to get an approximate idea of what the **breakeven value** would be. For example, in slide J5, NS for the heat pump would go to zero--and so make the decision maker indifferent between the baseboard system and the heat pump--if the annual electricity cost for the heat pump increased to over $1,000.

"What if" scenarios

Identifying critical input values and determining the range of economic measures answers a number of "what if" questions. Sensitivity analysis is a good technique for taking a closer look at the most plausible "what if" scenarios in order to be prepared to answer these types of questions when they arise during the decision-making process.

Spider diagrams   **Slide J9**

Spider diagrams combine several curves in one diagram and show the impact of different uncertain variables on a specific measure of economic evaluation. This is essentially a snapshot of the **relative importance** of inputs. The steeper the curve, the greater the impact. In slide J10, the sensitivity of NS is tested with respect to all the input values of the baseboard/heat pump example. The spider diagram confirms that it is energy costs that have the greatest impact on the life-cycle cost results.

Note that when you compare input values by means of a spider diagram, you are looking at the effect of each variable separately, with all others held constant. The same is true for graphs of combinations of values; each combination is independent of the others.

Advantages and disadvantages of sensitivity analysis

The results of sensitivity analysis can be presented in text, tables, or graphs. It is easy to perform and easy to understand, and requires no additional methods of computation beyond those already treated in the course.

The major disadvantages of sensitivity analysis are that it gives no probabilistic measure of the risk of choosing an uneconomic project, and it does not include an explicit measure of risk attitude. Sensitivity analysis can be misleading if all optimistic or pessimistic assumptions about input values are combined in calculating economic measures.

Breakeven analysis

Decision makers sometimes want to know the **maximum cost** of an input that will allow the project to still break even. Or, conversely, what **minimum benefit** a project can produce and still cover the cost of the investment.

To perform a breakeven analysis, benefits and costs are set equal, all variables are specified, except the breakeven variable, and **the breakeven variable is solved for algebraically.** In the baseboard/heat pump example, benefits consist of the present-value savings attributable to the heat pump, and costs are the total additional present-value investment costs; the difference in initial investment (ΔI) is the unknown variable solved for. In this example, the breakeven value for initial investment is $3,924, i.e., the investment cost for purchasing and installing a heat pump could be higher than the investment cost for the baseboard system by as much as $3,924, and the project would still break even. As for OM&R costs, it would be possible to pay up to $3,126 more in present-value OM&R costs for the heat pump before they would offset savings.

Advantages and disadvantages of breakeven analysis

An advantage of breakeven analysis is that it can be computed quickly and easily without additional information. The breakeven value can serve as a **benchmark value** to be compared against its predicted performance. Breakeven analysis can be especially useful for **screening** of alternatives prior to performing an LCC analysis.

A disadvantage of breakeven analysis is that it provides no probabilities of occurrence of the values of either input variables or measures of worth, and no explicit treatment of risk attitude.

Using expected values to estimate inputs

An "expected value" of an input is found by summing the products of likely input values and their respective probabilities of occurrence. The result is a **probability-weighted average** of several possible values for an input. The expected value is then used to compute a **single-value, deterministic** measure of economic worth. For example, our best-guess estimate of the annual electricity cost for the heat pump could have been arrived at by calculating its expected value. You might know--maybe from previous experience--that in 20 percent of the cases the annual energy cost for a heat pump turns out to be only $700, half the time $800, and in 30 percent of the cases it is as high as $900. The expected value for the annual energy cost would then be $810, close to the "best-guess" estimate used in the life-cycle cost analysis. This value is unlikely to be the actual value, but over repeated LCC analyses, the differences between actual values and predicted values is likely to be smaller than if point estimates are used.

PROBABILISTIC TECHNIQUES

Probability distributions   Slides J12 to J14

If the frequencies of **all likely values** of an input are recorded, a **probability distribution** can be derived whose values are then used, instead of the single-point estimate, as inputs into the calculation of any particular measure of worth (LCC, NS, SIR, etc.). For example, annual energy cost for heat pumps might be normally distributed with a mean of $800 and a standard deviation of $100. With a normal distribution, you know that there is about a 95 percent probability that the true mean lies within two standard deviations, i.e, between $600 and $1,000.

The graph in slide J13 shows actual heat pump data collected by American Electric Power in a survey of 2,184 heat pumps in seven states. The survey found that 93 percent of heat pumps were still in service after 10 years and 50 percent after 20 years. But note that the data from this survey is not sufficient to develop a probability distribution for heat pump life.

The probability distribution of an uncertain input value provides the basis for calculating any number of outcomes for the measure of worth and the probability of each of them occurring. The result of this calculation is a **probability distribution for the economic measure of worth**, with a mean and a standard deviation, similar to the one shown in slide J13. But in order to be able to say what the risk is of not achieving a particular NS, for example, or the chance of exceeding it, another step is necessary: a **cumulative probability distribution function** has to be generated by successively adding the probabilities of each NS value and plotting a **cumulative distribution curve.** Slide J14 shows such a (hypothetical) curve, generated for the NS of the heat pump. According to this curve, the risk of achieving an NS of less than zero is about 10 percent. Conversely, you can say that you have a 90 percent probability of achieving a positive NS.

Probability distributions can be developed for each individual input parameter so that a probability distribution for a measure of worth can be calculated based on **combinations of any number of uncertain input values.** In this case, a computer and computer software are needed to perform the calculations using a **simulation** procedure.

Monte Carlo Simulation   Slide J15

Monte Carlo simulation uses a simple technique of **sampling the probability distributions** of uncertain input values to obtain a close approximation to the true probability distribution of a measure of worth. It can be thought of as randomly selecting alternative combinations of input values, combining them with the certain input values, and calculating measures of worth for many--maybe hundreds or thousands--of trial scenarios.

The output of the Monte Carlo simulation is a frequency distribution displaying the full range of possibilities and approximating the true probability distribution. A corresponding cumulative distribution function, as in slide J14, can then be generated for any of the measures of worth from the probability distribution. In addition, these curves can be generated for **each project alternative** and then compared with each other to read off directly the **risk/return trade-offs for these alternatives.**

Advantages and disadvantages of simulation techniques

Monte Carlo simulation can use probability **distributions of any form** and generate curves **for each measure of worth and for each alternative.** The method models **in great detail** risk and uncertainties, including contingencies, to reflect the analyst's full understanding of the project. There is little cost to adding variables so that all possible eventualities can be modeled, if the probability distributions of the variables are known.

A disadvantage of the simulation technique is that a great many trials are necessary to assure accuracy. Large simulation models can be time-consuming and require a computer and appropriate software. The technique is difficult to document because the decision structure is not obvious. Risk attitude is not explicitly included.

Other Techniques   Slide J16

Techniques for Treating Uncertainty and Risk in the Economic Evaluation of Building Investments describes a number of techniques, both deterministic and probabilistic, with or without quantification of risk exposure and risk attitude, and offers suggestions as to when they are usefully applied.

RISK ATTITUDE IN THE FEDERAL GOVERNMENT

All of the techniques examined in this module include risk attitude only implicitly. It is assumed that decision makers accept or reject an alternative based on their subjective risk preference. For example, a probability of almost 90 percent that NS will be greater than zero may be acceptable to most decision makers unless they are very **risk averse.** Under certain circumstances, it may be appropriate to employ risk assessment techniques that use **utility functions** to quantify risk preferences of individuals, corporations, or institutions.

For federal projects the analyst generally does not have to be concerned about quantifying risk attitude. **The government is assumed to be risk neutral,** since it simultaneously invests in many projects, pooling its risk. Under these conditions, it is sufficient to **choose the alternative with the highest expected net savings.** Individual managers, however, may have a personal stake in the success of a project and may not make decisions based on expected value but based--at least in part--on their personal risk preference.

FEDERAL CRITERIA REGARDING UNCERTAINTY

If uncertainty analysis casts substantial doubt on the results of life-cycle cost analysis, federal agencies are advised to obtain more reliable input data, or eliminate the project.

Federal agencies are directed to use the DOE **energy price projections** and **discount rate** as published, without testing for sensitivity.

EXERCISE J1
Taking Into Account Uncertainties

Use LCC with sensitivity analysis to evaluate the cost effectiveness of retrofitting a computer room with a waste heat recovery system to supply part of the heating load of the building.Compute the break-even point in terms of contribution of waste heat recovery.

Data:

Location:	Wyoming
Building:	Federal building
Installed cost of waste heat recovery system:	$6,000
Annual OM&R cost of system:	$500
Heating Load:	900 MBtu
Existing fuel:	Natural Gas
Today's price:	$0.50/therm; commercial pricing (=$5.00/MBtu)
Efficiency of existing system:	0.65
Contribution of waste heat recovery to reducing the building's heating load:	25% (best guess) 10% (worst case)
Expected period of use:	Indefinite

COURSE EVALUATION

PURPOSE: It is our objective to present a useful and effective training course. You are the final authority on whether that objective has been met. Your completion of this form, therefore, will play an important part in our future planning. Please do not feel bound to limit your remarks to questions on this form. Your comments on any aspect of the course will be appreciated.

COURSE TITLE	Dates Attended
LOCATION	From To

RESPONSES (Check the response closest to your opinion)		Strongly Agree	Agree	Disagree	N/A
1. **Course Material Was**	a. well organized				
	b. complete and suitable				
	c. readable (printed well)				
2. **Audio-visual Material Was**	a. related to the course				
	b. good quality				
	c. sufficient in number				
3. **Course**	a. was a reasonable length				
	b. was worth recommending to others				
	c. contributed to my knowledge and skills				
	d. accomplished announced purpose				
4. **Instruction**	a. Subject was thoroughly covered				
	b. Course expectations, requirements, and objectives were made clear				
	c. Participation was encouraged				
	d. Time in class was spent effectively				
5. **Classrooms**	a. were comfortable				
	b. included a manageable number of students				
	c. were appropriate for this course				
6. **Instructors**	a. were prepared for class				
	b. stimulated my interest in subject area				
	c. made course a worthwhile learning experience				

REMARKS:

COURSE EVALUATION (Continued)

7. OVERALL INSTRUCTOR EVALUATION (Check your opinion)

a. Knowledge of the subject   ☐ Excellent   ☐ Good   ☐ Fair   ☐ Poor

b. Ability to teach   ☐ Excellent   ☐ Good   ☐ Fair   ☐ Poor

8. WOULD YOU ADD OR EMPHASIZE ANY SUBJECT MATTER AREAS IN SUBSEQUENT COURSE SESSIONS?

☐ yes   ☐ no   If "yes" list these areas and give your reasons:

9. WOULD YOU DELETE OR DE-EMPHASIZE ANY SUBJECT-MATTER AREAS?

☐ yes   ☐ no   If "yes" list these areas and give your reasons:

10. AS A RESULT OF YOUR PARTICIPATION IN THIS COURSE, WHAT ADDITIONAL RELATED TRAINING SHOULD BE MADE AVAILABLE?

11. OTHER COMMENTS. PLEASE MAKE ANY COMMENTS RELATIVE TO THIS COURSE, EITHER GENERAL OR SPECIFIC.

SIGNATURE AND TITLE (optional)	ORGANIZATION	DATE